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State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2011

État des ressources physiques et biologiques et de certaines ressources halieutiques des écosystèmes des eaux canadiennes du Pacifique en 2011

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ABSTRACT

The average global temperature in 2011 was warmer than average almost everywhere, but not in the eastern Pacific Ocean, where cool waters have been present in almost every year since 2008, part of a Pacific-wide weather pattern associated with La Niña conditions of these years. These La Niña conditions were most active in winter, with a stronger North Pacific High Pressure System and stronger, cool westerly winds over the ocean west of British Columbia. This pattern of cool ocean surface water was interrupted only briefly in the winter of 2010, when El Niño winds brought warmer waters to our region.

The North Pacific Current increased its eastward flow speed in the eastern North Pacific Ocean through the winter of 2011 to 2012, with normal flow otherwise. This current is expected to carry tsunami debris from Japan. Although some objects have already arrived, it is expected that the main part will arrive next winter or through 2013.

Sea surface measurements from shore stations along the coast of British Columbia, and in the Strait of Georgia, confirm that ocean conditions were cooler and also fresher in 2011 than in 2010. Relatively fresh surface waters within the Strait of Georgia in 2011 were at least partly a consequence of a heavy snow pack. Ocean surface waters on the British Columbia continental shelf were fresher than normal in the summer of 2011.

Weather conditions in late winter and early spring determine the timing and intensity of growth of phytoplankton that feed the food chain that provides necessary prey for juvenile fish at a critical time in their life. The spring bloom of phytoplankton in the Strait of Georgia in 2011 was later than normal, due to stronger winds of March, but once it began the growth was unusually strong. Observations of this bloom by satellite and by ship-based surveys reveal that it peaked in June and extended into July, and had unusually high biomass of the harmful algae *Heterosigma akashiwo*. Blooms of this phytoplankton have been observed in previous years in nearshore waters of the Strait of Georgia during May through October and have been postulated as perhaps adversely affecting juvenile sockeye salmon during their seaward migration.

Studies of zooplankton are undertaken along the west coast and in the Gulf of Alaska. These tiny drifting animals feed mainly on phytoplankton, and in turn are prey for many juvenile fish. The species composition of zooplankton and their biomass are useful predictors for fisheries. The copepod community of zooplankton on the Oregon continental shelf was dominated by lipid rich "northern" copepods in 2011, suggesting strong survivals for coho and Chinook salmon returning to the Columbia River in 2012 and 2013.

Further north, off the west coast of Vancouver Island, the zooplankton community was of normal composition, except for a summer shift to warm-water oceanic zooplankton seaward of the southern Vancouver Island shelf. In deep-sea waters, zooplankton indices were consistent with cool ocean conditions. When the zooplankton community composition is combined with other environmental indicators for the west coast of Vancouver Island and Oregon, 2011 conditions for juvenile salmon migrating to sea were rated as average. This rating affects Columbia River salmon as well as those from Vancouver Island itself.

Within the Strait of Georgia, conditions in 2011 were generally favourable for juvenile sockeye salmon from the Fraser River, whereas poor returns are projected for coho salmon returning in 2012, Chinook salmon returning in 2013 and 2014, and chum salmon returning in 2013.

An estimated 5 million Fraser River sockeye returned to British Columbia coastal waters in 2011, well within the range of the prediction provided the previous year. This number contrasts with the record high of about 30 million in 2010 and record low of 1 million in 2009. Lower returns in 2011 compared to 2010 are attributed mainly to reduced survival of young salmon in freshwater. The primary estimator of numbers of sockeye returns is based on the number of parent spawners four years earlier, because most sockeye return to their natal river at age four, after spending two years at sea and two years in freshwater. On this basis, the prediction for 2012 returns is 0.7 million to 7 million, at the 10% to 90% probability distribution. These numbers are lower than average, due to fewer spawning sockeye in 2008. Fraser River sockeye returns in 2013 might be lower than average as well, due to fewer parent spawners in 2009, combined with generally favourable conditions in the Strait of Georgia in 2011, noted previously.

As part of ongoing research into year-to-year changes in ocean conditions and their impact on salmon survival at sea, scientists have examined survivals of a single stock of sockeye, from Chilko Lake in the Fraser River basin. By comparing returns of the small numbers of those returning at age five with the larger numbers returning at age four, they have revealed a sharp pattern break in 1990, when the trend in marine survival changed from increasing prior to 1990 to decreasing after 1990. In contrast, marine survivals for Fraser pink salmon were without trend, and recent increases in pink salmon returns were determined to be primarily the result of reduced fishing. Another research effort, using ecosystem models that include most marine species and climate variability in the Strait of Georgia, identified a shift to lower growth rate of phytoplankton beginning in 1990 and continuing to present that is attributed to stronger wind speeds in spring and summer since 1990. This lower primary production is manifested in the model as declines, after 1990, of coho and Chinook salmon, herring, dogfish, and killer whales.

Other biological findings in 2011 include decreased pink shrimp biomass west of Vancouver Island from higher values in 2009 and 2010, likely as a result of warmer waters in spring two years previously when the shrimp were young.

Biomass indices for most groundfish species in Hecate Strait and Queen Charlotte Sound are trending upwards after several years of decline.

Eulachon populations coast-wide are at low levels, while Pacific sardine biomass off the west coast of Vancouver Island increased in 2011 compared to 2010. Herring biomass forecasts for Haida Gwaii and Central Coast stocks are below fishery thresholds, while for Strait of Georgia and Prince Rupert stocks, forecasts are above thresholds.

Length-at-age and weight-at-age of post-recruit herring has decreased in all BC populations since the 1970s, including herring populations not fished during the herring roe fishery. Similar changes have occurred in California and some, but not all SE Alaska herring populations. Because size-at-age has decreased in areas not fished, this decrease is not believed to be due to fishing.

Birds can be effective indicators of the state of marine ecosystems because their large breeding aggregations can be relatively easily counted. Breeding success of Triangle Island Cassin's Auklets is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus.* Breeding success of these auklets in 2011 was better than the long-term average and well above that of 2010.

In Pacific Rim National Park Reserve, 2011 seabird abundance remained high and similar to 2010. Most species displayed stable or improving population trends over the past 4 to 5 years.

Intertidal bivalve population abundances in the Barkley Sound part of this reserve were about average relative to previous years. Manila clams continue to decline while there appears to be no spatial displacement of this species by the recently introduced varnish clams. SARA-listed Olympia oyster has displayed a recovering trend for the past 7 years but the numbers are still below those observed in late 1990s.

Persistent, bioaccumulative and toxic contaminants present a health risk to aquatic biota, notably those at the top of food web such as killer whales and seals. Recent analyses of biopsy samples taken from young harbour seals live-captured in the Salish Sea reveal that polychlorinated biphenyls (PCBs) declined by 81% between 1984 and 2009 In contrast, the concentration of polybrominated diphenyl ethers (PBDEs) increased, with indication of a peak in PBDE levels in seals between 2003 and 2009 followed by a decline. This pattern would be consistent with the 2004 phase-out of two of the three PBDE products in Canada and the USA.

Airborne surveys for oil on British Columbia waters have operated with increased efficiency since 2006, when more accurate sensors were added to the surveillance aircraft flights by Transport Canada, as part of the National Aerial Surveillance Program. Observations by this program, together with modelling and analyses of these observations from 2006 to 2010 by the Canadian Wildlife Service, reveal that the highest relative likelihood of detecting oil discharges occurred close to shore and, in particular, in the Strait of Georgia, the inside passage of the central coast, near Prince Rupert, and in Alberni Inlet. Although results are preliminary, results suggest that marina densities and intensity of local vessel activity (as opposed to international shipping) generally determine oil discharge patterns in the Pacific Region. There is some evidence that oil discharges have declined since the program was enhanced in 2006.

Scientists have reported alarmingly low oxygen concentrations in near-shore waters of the Oregon coast in summer, beginning in 2002 and most severely in 2006. High crab mortalities on the ocean bottom took place in these summers. Low oxygen concentrations (less than 1 ml/L) have also been observed on off southwest Vancouver Island since 2002, with concentrations of 0.7 ml/L at 150 metres depth recorded in 2006 and 2009, the lowest in the 50-year record. Concentration was 1.0 and 1.1 ml/L in 2010 and 2011, respectively. Hypoxia on the Canadian shelf is much less severe than off Oregon and Washington, and mortality of bottom life has not been reported.

Deep water in the North Pacific Ocean already has the most acidic water in the global ocean and the British Columbia continental shelf might see negative impacts of this feature sooner than most oceanic waters.

Scientists hope to collaborate in the next year to produce more quantitative ocean indices to rank the health of the ocean and its marine species, as part of an ongoing ecosystem approach to management (EAM). This will require scientists to develop a new suite of tools and products to advise resource managers on the impact and management options for human activities in the marine environment. Subsequent State of Ocean workshops and reports are expected to report on the continued development of ecosystem indicators.

RÉSUMÉ

La température moyenne mondiale en 2011 a été plus élevée que la moyenne à peu près partout, sauf dans l'est de l'océan Pacifique où des eaux fraîches ont été présentes presque tous les ans depuis 2008, situation en partie causée par le modèle de conditions météorologiques observé dans tout le Pacifique et associé aux effets de La Niña pendant cette période. Les effets de La Niña se sont fait davantage sentir pendant l'hiver; un système plus fort de haute pression a été présent dans le Pacifique Nord et des vents frais de l'ouest plus violents ont soufflé sur l'océan à l'ouest de la Colombie-Britannique. Ce modèle d'eau de surface océanique fraîche n'a été interrompu que brièvement au cours de l'hiver 2010, alors que les vents d'El Niño ont poussé des eaux plus chaudes vers notre région.

Le courant du Pacifique Nord a augmenté sa vitesse vers l'est, dans la partie est du Pacifique Nord, pendant l'hiver 2011-2012; autrement, le courant était normal. Il devrait transporter des débris du tsunami survenu au Japon. Bien que certains objets soient déjà arrivés, on prévoit que la majeure partie des débris arrivera l'hiver prochain ou en 2013.

Les mesures des eaux océaniques de surface aux stations côtières le long de la côte de la Colombie-Britannique et dans le détroit de Georgie confirment que les eaux de l'océan ont été plus fraîches et moins salées en 2011 qu'en 2010. Les eaux de surface relativement douces dans le détroit de Georgie, en 2011, étaient en partie attribuables aux fortes accumulations de neige. Les eaux océaniques de surface sur le plateau continental de la Colombie-Britannique ont été plus douces que la normale à l'été 2011.

Les conditions météorologiques à la fin de l'hiver et au début du printemps déclenchent le début de la croissance du phytoplancton et définissent son intensité. Dans la chaîne alimentaire, ce phytoplancton sert de nourriture aux proies consommées par les poissons juvéniles à un moment important de leur vie. La prolifération printanière du phytoplancton dans le détroit de Georgie a été plus tardive en 2011 à cause des vents violents qui ont soufflé en mars mais une fois commencée, elle a été exceptionnellement forte. Les observations de cette prolifération, effectuées par satellite et sous forme de relevés faits par bateau, révèlent l'apparition d'un pic en juin, qui s'est prolongé jusqu'en juillet, ainsi que la présence d'une biomasse exceptionnellement importante de l'algue nuisible *Heterosigma akashiwo.* La prolifération de ce phytoplancton a été observée au cours des dernières années dans les eaux côtières du détroit de Georgie, de mai à octobre, et a été accusée de possiblement nuire au saumon rouge juvénile lors de sa migration vers la mer.

Des études sur le zooplancton ont été entreprises le long de la côte ouest et dans le golfe de l'Alaska. Ces minuscules animaux qui dérivent dans l'eau se nourrissent principalement de phytoplancton et deviennent par la suite les proies de nombreux poissons juvéniles. La composition, par espèce, du zooplancton et sa biomasse sont des indicateurs utiles pour les pêches. La communauté de copépodes qui vit dans le zooplancton du plateau continental de l'État de l'Oregon a été dominée en 2011 par la présence de copépodes nordiques, riches en lipides, ce qui laisse présager un fort taux de survie des saumons coho et quinnat qui retourneront dans le fleuve Columbia en 2012 et en 2013.

Plus au nord, au large de la côte ouest de l'île de Vancouver, la communauté de zooplancton présentait une composition normale, sauf lors de l'apparition, pendant l'été, de zooplancton océanique provenant des eaux chaudes au sud du plateau de l'île de Vancouver. Dans les eaux océaniques profondes, les indicateurs de zooplancton correspondaient aux conditions fraîches de l'océan. Au large de la côte ouest de l'île de Vancouver et de l'État de l'Oregon, la composition de la communauté de zooplancton, combinée à d'autres indicateurs environnementaux, a permis de classer comme moyennes les conditions pour les saumons

juvéniles migrant vers la mer. Cette classification concerne le saumon du fleuve Columbia et de l'île de Vancouver.

Dans le détroit de Georgie, les conditions de 2011 ont en général été favorables pour le saumon rouge juvénile du fleuve Fraser, alors que les projections indiquent de faibles taux de retours pour le saumon coho en 2012, pour le saumon quinnat en 2013 et en 2014, et pour le saumon kéta en 2013.

Environ 5 millions de saumons quinnat du fleuve Fraser sont retournés dans les eaux côtières de la Colombie-Britannique en 2011, tout à fait dans la fourchette de prévisions fournie l'année précédente. Ce nombre contraste avec le record élevé d'environ 30 millions en 2010 et le nombre minimal d'un million en 2009. Le faible taux de retour observé en 2011, comparé à celui de 2010, est principalement attribué au taux réduit de survie des jeunes saumons en eau douce. Le principal estimateur du nombre de retours du saumon rouge se base sur le nombre de géniteurs quatre ans auparavant, car la plupart des saumons rouges retournent dans leur rivière natale à l'âge de quatre ans, après avoir passé deux ans en mer et deux ans en eau douce. Sur cette base, la fourchette de prévisions, pour une distribution de probabilités se situant entre 10 % et 90 %, donne un nombre de retours en 2012 compris entre 0,7 et 7 millions de saumons rouges. Ces chiffres sont plus bas que la moyenne et s'expliquent par la diminution du nombre de saumons rouges géniteurs en 2008. Le taux de retour du saumon rouge du fleuve Fraser, en 2013, pourrait aussi être inférieur à la moyenne à cause du faible nombre de parents géniteurs en 2009 et des conditions généralement favorables dans le détroit de Georgie en 2011, tel qu'il a été mentionné précédemment.

Dans le cadre d'une étude permanente sur les changements annuels de l'état de l'océan et leurs effets sur le taux de survie du saumon en mer, les scientifiques ont examiné les taux de survie d'un stock précis de saumon rouge, qui provient du lac Chilko dans le bassin du fleuve Fraser. En comparant les retours du petit nombre de saumons retournant à l'âge de cinq ans aux retours de ceux retournant à l'âge de quatre ans, l'étude a révélé un brusque écart en 1990 par rapport au modèle, alors que la tendance des taux de survie marins s'est inversée, passant d'un taux en croissance avant 1990 à un taux décroissant après 1990. En revanche, le taux de survie marin du saumon rose du fleuve Fraser n'affichait pas de tendance marquée et les récentes augmentations de retours de saumons roses ont été attribuées principalement à la réduction de la pêche. Une autre recherche, réalisée à partir de modèles écosystémiques incluant la plupart des espèces marines et la variabilité du climat dans le détroit de Georgie, a permis de déceler un changement à la baisse du taux de croissance du phytoplancton, changement amorcé dès les années 1990 qui se poursuit à l'heure actuelle et est attribué à des vents plus forts au printemps et à l'été depuis 1990. Cette plus faible production primaire se manifeste, dans le modèle, comme une diminution, après 1990, pour les saumons coho et quinnat, le hareng, le chien de mer et les épaulards.

L'année 2011 a vu une diminution de la biomasse de crevettes nordiques à l'ouest de l'île de Vancouver, par rapport aux fortes quantités des années 2009 et 2010. Cette situation résulte probablement d'un printemps aux eaux plus chaudes, survenu deux ans auparavant; ces eaux chaudes ont nui à la survie des jeunes crevettes

Les indices de la biomasse pour la plupart des espèces de poissons de fond dans le détroit d'Hecate et dans le détroit de la Reine-Charlotte montrent une tendance à la hausse, après plusieurs années de déclin.

Les populations d'eulachons demeurent faibles partout sur la côte, tandis que la biomasse de sardines du Pacifique, au large de la côte ouest de l'île de Vancouver, a augmenté en 2011 par rapport à 2010. Les prévisions de biomasse de hareng pour les stocks de Haida Gwaii et de la Côte centrale se situent sous le seuil de pêche, mais au-dessus pour les stocks du détroit de Georgie et de Prince Rupert.

La longueur et le poids selon l'âge pour le hareng recruté ont diminué depuis les années 1970 dans toutes les populations de la Colombie-Britannique, y compris les populations de hareng non pêchées lors de la pêche au hareng rogué. Des changements semblables sont survenus en Californie et dans certaines populations de hareng du sud-est de l'Alaska, mais pas toutes. Puisque cette diminution de la taille selon l'âge se produit dans des zones où il n'y a pas eu de pêche, on ne peut pas l'attribuer à la pêche.

Les oiseaux peuvent servir d'indicateurs efficaces de l'état des écosystèmes marins, car leurs vastes regroupements de reproducteurs sont relativement faciles à dénombrer. Le taux de succès de reproduction du starique de Cassin habitant l'île Triangle est fortement corrélé, dans le temps, avec la phénologie d'une proie importante, le copépode *Neocalanus cristatus*. En 2011, il a été supérieur à la moyenne à long terme et bien supérieur à celle de 2010.

Dans la réserve du parc national Pacific Rim, l'abondance d'oiseaux de mer en 2011 est demeurée élevée, semblable à celle de 2010. La population de la plupart des espèces a affiché une tendance stable ou à la hausse au cours des 4 à 5 dernières années. Le nombre de bivalves intertidaux de la réserve vivant dans la section du détroit de Barclay se situait dans la moyenne par rapport au niveau des années précédentes. Le déclin des palourdes japonaises se poursuit, alors qu'on ne dénote aucun déplacement spatial de cette espèce causé par la récente introduction de palourdes *Nuttalia obscurata*. L'huître plate du Pacifique, protégée par la LEP, affiche une tendance au rétablissement depuis sept ans, mais les stocks n'ont pas encore retrouvé les niveaux observés à la fin des années 1990.

Les contaminants persistants, biocumulatifs et toxiques constituent un risque pour la santé des biotes aquatiques, notamment ceux qui se situent en haut de la chaîne alimentaire comme les épaulards et les phoques. Les analyses récentes de prélèvements par biopsie pratiqués sur de jeunes phoques communs, capturés vivants dans la mer de Salish, révèlent que la quantité de biphényles polychlorés (BPC) chez ces individus a diminué de 81 % entre 1984 et 2009. En revanche, la concentration de polybromodiphényléthers (PBDE) a augmenté, avec l'indication d'un pic des niveaux de PBDE chez ces individus entre 2003 et 2009, suivi d'une diminution. Cette tendance correspondrait à l'élimination progressive, à partir de 2004, de deux des trois produits utilisant des PBDE offerts sur les marchés canadien et américain.

Les levés aériens liés à la recherche d'hydrocarbures dans les eaux de la Colombie-Britannique sont plus efficaces depuis 2006, Transports Canada ayant installé des capteurs plus précis à bord des appareils aériens de surveillance dans le cadre du Programme national de surveillance aérienne. Les observations réalisées dans le cadre de ce Programme, combinées à la modélisation et aux analyses de ces observations faites entre 2006 et 2010 par le Service canadien de la faune, révèlent que la plus grande probabilité de détection de déversements d'hydrocarbures se situe près de la côte et, plus précisément, dans le détroit de Georgie, dans le passage intérieur de la Côte centrale, près de Prince-Rupert, et dans le passage Alberni. Bien qu'il s'agisse de résultats préliminaires, on peut penser que la densité des marinas et l'intensité des activités des navires locaux (par opposition au transport international) définissent généralement les modèles de déversements d'hydrocarbures dans la région du Pacifique. Il existe quelques preuves que le nombre de déversements d'hydrocarbures a diminué depuis l'amélioration du programme en 2006.

Les scientifiques ont signalé que des concentrations en oxygène extrêmement faibles ont été relevées pendant l'été dans les eaux côtières de la côte de l'État de l'Oregon depuis 2002, le niveau le plus alarmant ayant été atteint en 2006. Un taux de mortalité élevé chez les crabes vivant au fond de l'océan est survenu au cours de ces étés. De faibles concentrations en oxygène (moins de 1 ml/l) ont aussi été observées au large de la côte sud-ouest de l'île de Vancouver depuis 2002, avec des concentrations de 0,7 ml/l à 150 m de profondeur. Cette concentration, relevée en 2006 et en 2009, est la plus basse enregistrée depuis les

50 dernières années. La concentration était de 1,0 et 1,1 ml/l en 2010 et en 2011 respectivement. L'hypoxie sur le plateau canadien est bien moins grave qu'au large des États de l'Oregon et de Washington; la mortalité de la faune et de la flore marine du fond de l'océan n'a pas fait l'objet de rapport.

L'eau profonde du Pacifique Nord est déjà la plus acide de tous les océans et le plateau continental de la Colombie-Britannique en souffrira sans doute bien avant la plupart des eaux océaniques.

Les scientifiques espèrent collaborer l'année prochaine en vue de définir plus d'indicateurs océaniques quantitatifs qui serviront à classer l'état de santé de l'océan et de ses espèces marines, dans le cadre d'une approche écosystémique permanente de gestion. Pour ce faire, ils devront élaborer un ensemble d'outils et de produits pour informer les gestionnaires de ressources sur les répercussions et les options de gestion des activités humaines dans l'environnement marin. Des ateliers et des rapports subséquents sur l'état des océans rendront compte de l'élaboration continue des indicateurs relatifs aux écosystèmes.

1 INTRODUCTION

This report is the thirteenth in an annual series on the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by scientific staff in several government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, Environment Canada, Parks Canada and the Department of National Defence. Additional information is provided by the US National Oceanographic and Atmospheric Administration (NOAA), University of Victoria, and the University of British Columbia.

Information for this report was presented at the annual workshop of the Fisheries Oceanography Working Group (FOWG) at the Vancouver Island Conference Centre, Nanaimo, BC, on February 15 to 16, 2012 chaired by Jim Irvine and Bill Crawford, both of Fisheries and Oceans Canada. They subsequently produced this summary report based on contributions by participants. Participants at the workshop are thanked for their contributions, especially those who contributed individual reports, and special thanks goes to Sarah Archibald for her hard work and attention to detail in helping to produce this report.

1.1 2011 ASSESSMENT HIGHLIGHTS

Important highlights from the more detailed individual reports follow. The relevant individual reports are linked, with the author of each report indicated in blue.

1.1.1 Eastern Pacific Relatively Cool and Fresh

The average global temperature in 2011 was warmer than average almost everywhere, but not in the eastern Pacific Ocean (Crawford, Robert et al.). Fig.1 shows the extent to which temperature was warmer (red) or cooler (blue) in 2011 compared to the reference period of 1971 to 2001. Local cooling in the eastern Pacific Ocean has been present in almost every year since 2008, part of a Pacific-wide weather pattern associated with La Niña conditions of these years. This pattern of cool ocean surface water was interrupted only briefly in the winter of 2010, when El Niño winds brought warmer waters to this region.

A generally weaker-than-average Aleutian Low and stronger-than-average North Pacific High resulted in stronger than average upwelling-favourable (northwesterly) winds in summer along the coast of British Columbia that have persisted since the late 1990s (Hourston and Thomson). The North Pacific Current increased its eastward flow speed in the eastern North Pacific Ocean through the winter of 2011 to 2012, with normal flow otherwise. This current is expected to carry tsunami debris from Japan. Although some objects have already arrived, it is expected that the main part will arrive next winter or through 2013 (Robert et al.).

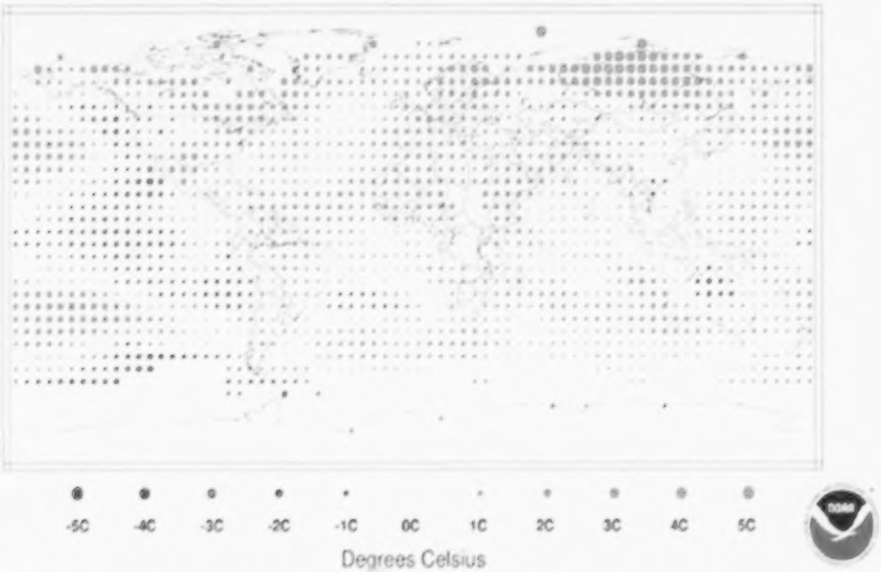


Figure 1. Annual surface temperature anomaly for 2011 (°C). relative to 1971 to 2000. Image provided by the National Climate Data Center of NOAA of the US National Oceanic and Atmospheric Administration. (from Crawford).

Sea surface measurements from shore stations along the coast of British Columbia, and in the Strait of Georgia, confirm that ocean conditions were cooler (Fig. 2), and also fresher in 2011 (Fig. 3) than a long-term average. Sea surface temperature continues a long-term trend to warmer conditions, but at a reduced rate since 2006. Subsurface waters within the Strait of Georgia were also cooler and fresher in 2011 (Masson and Cummins).

Relatively fresh waters within the Strait of Georgia were at least partly a consequence of a heavy snow pack, followed by a mild spring and summer that delayed and extended the freshet in 2011 (Dewey). Ocean surface waters on the British Columbia continental shelf were fresher than normal in the summer of 2011 (Chandler).

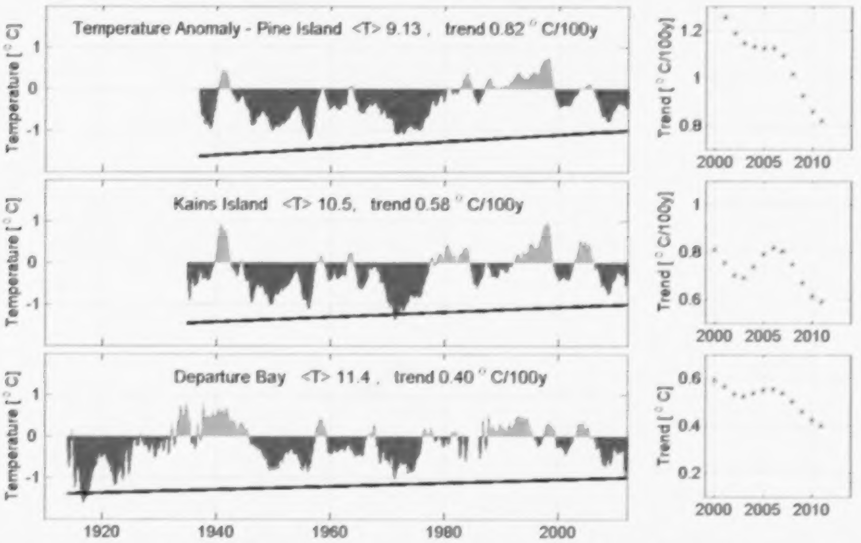


Figure 2. Long-term time series of daily temperature anomalies, averaged over 12 months, at stations representing the north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average temperature <T> are shown in red (blue). The panel to the right shows the slope of the trend (black line) calculated using only data up to the year shown on the x axis (from Chandler).

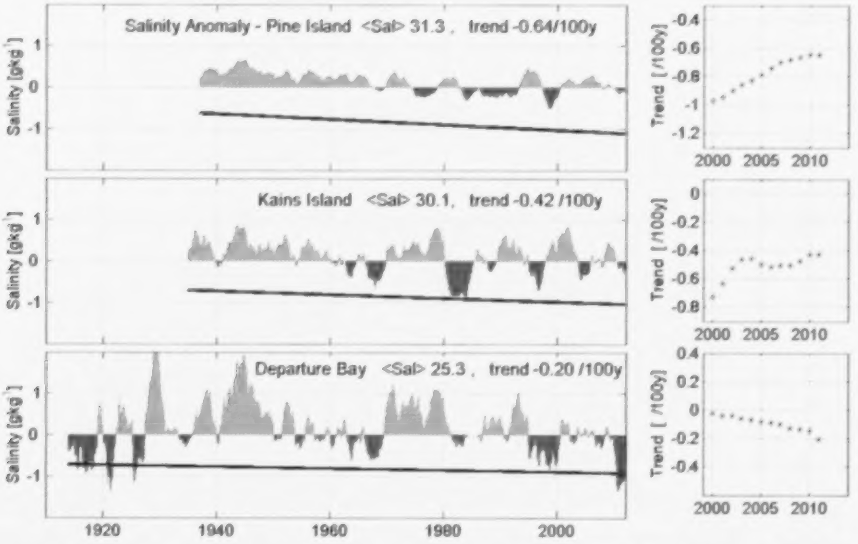


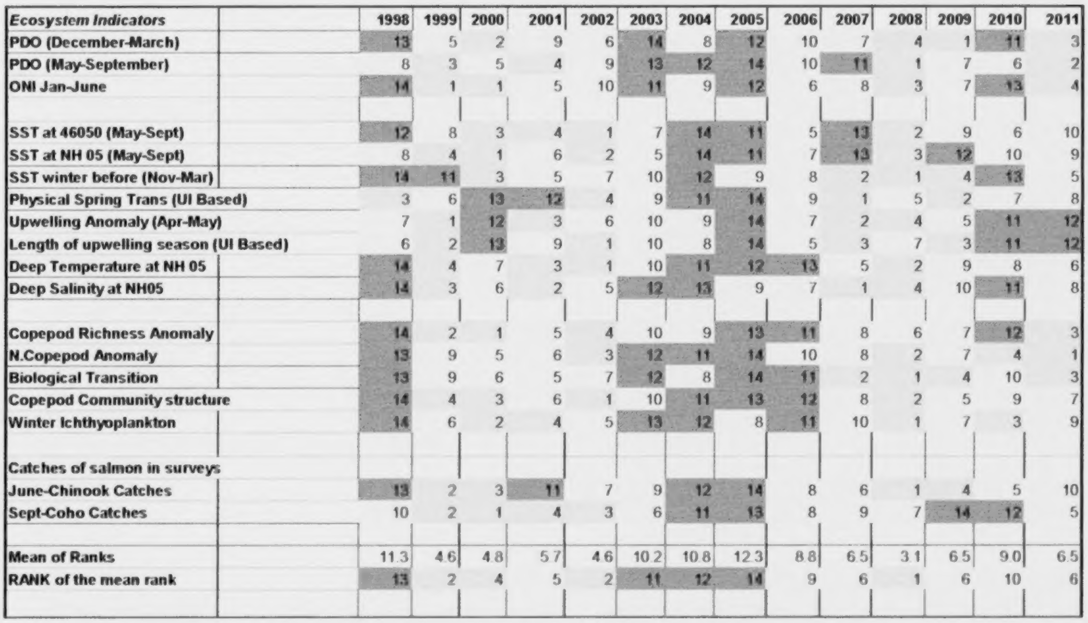
Figure 3. Long-term time series of daily salinity anomalies averaged over 12 months, for north coast, west coast and Strait of Georgia stations. Positive-saltier (negative-fresher) anomalies from the average salinity <Sal> are shown in red (blue). The panel to the right shows the slope of the trend (black line) calculated using only data up to the year shown on the x axis (from Chandler).

1.1.2 Strait of Georgia Algal Bloom Late But Intense and *Heterosigma* Abundant in Summer

The 2011 spring bloom within the Strait of Georgia was late (Allen and Latornell, Gower and King) and intense. High chlorophyll levels in summer (Gower and King) were the result of a bloom of the harmful algae *Heterosigma akashiwo* (Peña). Blooms of this phytoplankton have been observed in nearshore waters of the Strait of Georgia during May through October and have been postulated as perhaps adversely affecting juvenile sockeye salmon (Peña).

1.1.3 Ecosystem Indicators Suggest Generally Average Salmon Survivals For Fish Entering Sea in 2011

Despite a strongly negative Pacific Decadal Oscillation (PDO) in 2011, upwelling off Oregon was relatively weak in April and May, strengthened moderately in mid June but then ended in mid September, resulting in the cumulative upwelling being the 12th lowest value since 1998 (Peterson). Despite the relatively low upwelling, the copepod community of zooplankton on the Oregon continental shelf was dominated by lipid rich "northern" copepods, suggesting strong survivals for coho and Chinook salmon returning in 2012 and 2013 respectively.



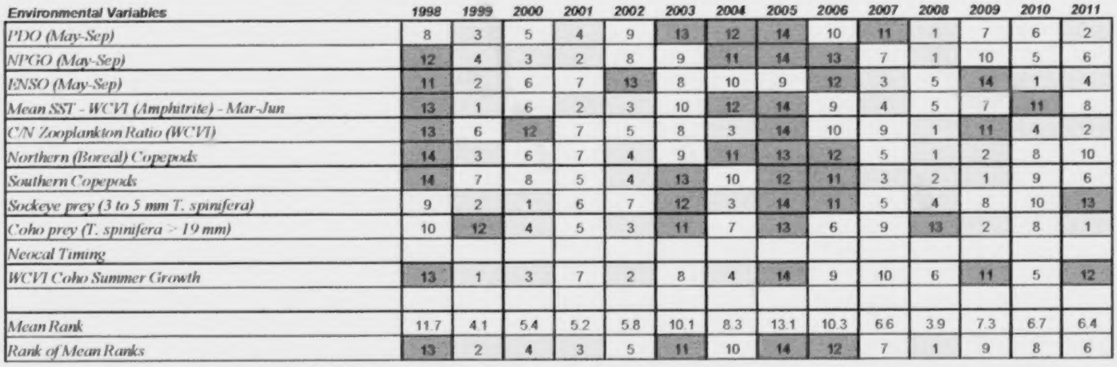
Ecosystem Indicators	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PDO (December-March)	13	5	2	9	6	14	8	12	10	7	4	1	11	3
PDO (May-September)	8	3	5	4	9	13	12	14	10	11	1	7	6	2
ONI Jan-June	14	1	1	5	10	11	9	12	6	8	3	7	13	4
SST at 46050 (May-Sept)	12	8	3	4	1	7	14	11	5	13	2	9	6	10
SST at NH 05 (May-Sept)	8	4	1	6	2	5	14	11	7	13	3	12	10	9
SST winter before (Nov-Mar)	14	11	3	5	7	10	12	9	8	2	1	4	13	5
Physical Spring Trans (UI Based)	3	6	13	12	4	9	11	14	9	1	5	2	7	8
Upwelling Anomaly (Apr-May)	7	1	12	3	6	10	9	14	7	2	4	5	11	12
Length of upwelling season (UI Based)	6	2	13	9	1	10	8	14	5	3	7	3	11	12
Deep Temperature at NH 05	14	4	7	3	1	10	11	12	13	5	2	9	8	6
Deep Salinity at NH05	14	3	6	2	5	12	13	9	7	1	4	10	11	8
Copepod Richness Anomaly	14	2	1	5	4	10	9	13	11	8	6	7	12	3
N.Copepod Anomaly	13	9	5	6	3	12	11	14	10	8	2	7	4	1
Biological Transition	13	9	6	5	7	12	8	14	11	2	1	4	10	3
Copepod Community structure	14	4	3	6	1	10	11	13	12	8	2	5	9	7
Winter Ichthyoplankton	14	6	2	4	5	13	12	8	11	10	1	7	3	9
Catches of salmon in surveys														
June-Chinook Catches	13	2	3	11	7	9	12	14	8	6	1	4	5	10
Sept-Coho Catches	10	2	1	4	3	6	11	13	8	9	7	14	12	5
Mean of Ranks	11.3	4.6	4.8	5.7	4.6	10.2	10.8	12.3	8.8	6.5	3.1	6.5	9.0	6.5
RANK of the mean rank	13	2	4	5	2	11	12	14	9	6	1	6	10	6

Figure 4. Ocean system indicators for the Oregon continental shelf (Peterson) showing the ranks of the indicators used to provide outlooks of returns of coho and Chinook salmon to the Columbia River. Green-coloured boxes and low ranks indicate "good ocean conditions" from the viewpoint of a salmon. Yellow denotes average ocean conditions; red indicates poor. The overall "integrated" indicator is the "RANK of the mean rank" on the bottom line of the table, and for 2011, suggests that this was an "average" year. The values behind the ranks can be seen on the "Ocean Conditions" website:http://www.nwfsc.noaa.gov and click on "Ocean Conditions and Salmon Forecasts" in the box on the right-hand side of the webpage.

Copepod community composition is only one of the ecosystem indicators routinely used to forecast coho and Chinook salmon survivals in Oregon (Fig. 4); the overall forecast for salmon going to sea in 2011 is for average survivals. (The yellow cell in lower right corner of Fig. 4 is ranked 6 out of 14 years.)

Further north, off the west coast of Vancouver Island, Mackas rated the zooplankton community as "near average" except for a summer shift to warm-water oceanic zooplankton seaward of the southern Vancouver Island shelf break. Based on Continuous Plankton Recorder samples from the spring of 2011, Batten's zooplankton biomass, timing, and composition indices are consistent with cool ocean conditions, well within the range seen earlier in her time series.

When zooplankton community composition is combined with other environmental indicators for the West Coast of Vancouver Island, 2011 conditions for outmigrating juvenile salmon were rated as average (i.e. yellow) by Trudel et al. (Fig. 5).



Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PDO (May-Sep)	8	3	5	4	9	13	12	14	10	11	1	7	6	2
NPGO (May-Sep)	12	4	3	2	8	9	11	14	13	7	1	10	5	6
ENSO (May-Sep)	11	2	6	7	13	8	10	9	12	3	5	14	1	4
Mean SST - WCVI (Amphitrite) - Mar-Jun	13	1	6	2	3	10	12	14	9	4	5	7	11	8
C/N Zooplankton Ratio (WCVI)	13	6	12	7	5	8	3	14	10	9	1	11	4	2
Northern (Boreal) Copepods	14	3	6	7	4	9	11	13	12	5	1	2	8	10
Southern Copepods	14	7	8	5	4	13	10	12	11	3	2	1	9	6
Sockeye prey (3 to 5 mm T. spinifera)	9	2	1	6	7	12	3	14	11	5	4	8	10	13
Coho prey (T. spinifera > 19 mm)	10	12	4	5	3	11	7	13	6	9	13	2	8	1
Neocal Timing														
WCVI Coho Summer Growth	13	1	3	7	2	8	4	14	9	10	6	11	5	12
Mean Rank	11.7	4.1	5.4	5.2	5.8	10.1	8.3	13.1	10.3	6.6	3.9	7.3	6.7	6.4
Rank of Mean Ranks	13	2	4	3	5	11	10	14	12	7	1	9	8	6

Figure 5. Ocean ecosystem indicators for the west coast of Vancouver Island. Indicators are ranked from one (best for salmon) to fourteen (worst for salmon), and colour-coded green and red for best and worst conditions for salmon respectively, yellow for neutral conditions (From Trudel et al.)

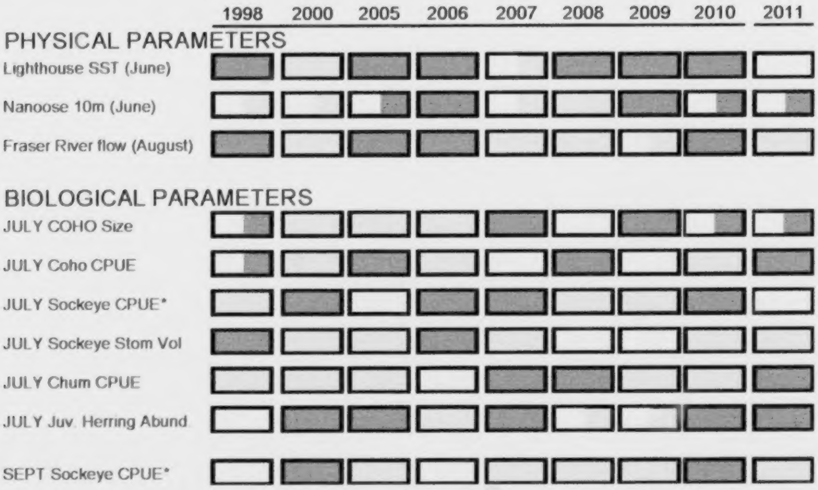


Figure 6. Red light grid for ocean indicators for the Strait of Georgia (from Sweeting).

Within the Strait of Georgia, Sweeting found conditions in 2011 generally favourable (green) for sockeye salmon (Fig. 6), while indicators for other species are less favourable (yellow and green). Based on 2011 data, Sweeting projects poor returns for coho salmon returning in 2012, Chinook returning in 2013 and 2014, and chum salmon returning in 2013.

1.1.4 Freshwater as well as Marine Survival Patterns Important in Determining Salmon Abundance

Since many salmon survival time series are based only on spawner abundance estimates during successive generations, it is not possible to separate out the relative role of mortalities in freshwater versus the ocean. Fortunately this can be done for Chilko Lake (Fraser) sockeye and Fraser pink salmon. Numbers of young Chilko Lake sockeye are estimated as they depart Chilko Lake on their seaward migration down the Fraser River system, and adults are counted upon their return from the ocean two years later, allowing scientists to determine their post-smolt survival. No other major Fraser River sockeye run is assessed in this manner. Survival estimates for Fraser River pink salmon are less reliable than for Chilko sockeye salmon. An index of outmigrating fry abundance is available from a monitoring program in the lower river, and several approaches have been used to estimate spawner numbers during the time series.

Grant and Irvine et al. demonstrate that mortalities early in the life history of these salmon, before they begin their downstream migration to sea, play a major role in determining overall survivals. Sockeye salmon survivals within Chilko Lake declined for ~20 yrs commencing in the 1970's while Fraser pink salmon freshwater survivals have been declining for most of the last 30 yrs. In their assessment of 2010 and 2011 mortalities for young Chilko sockeye salmon en route to sea and during their early marine migration, Rechisky et al. documented highest mortalities during the initial downstream riverine migration between Chilko Lake and the Fraser River.

Irvine et al. examined the smolt survival time series for two smolt age classes of Chilko sockeye salmon. They were able to eliminate the noise in survival estimates sufficiently to reveal a sharp pattern break in 1990, when the trend in survival changed from increasing prior to 1990 to decreasing after 1990. In contrast, marine survivals for Fraser pink salmon were without trend, and recent increases in pink salmon returns were determined to be primarily the result of reduced fishing (Irvine et al.).

1.1.5 Modest Returns of Fraser Sockeye in 2011

An estimated 5 million Fraser River sockeye returned to British Columbia coastal waters in 2011, well within the range of the prediction provided the previous year (Grant). This number contrasts with the record high of about 30 million in 2010 and record low of 1 million in 2009. Lower returns in 2011 compared to 2010 year are attributed mainly to reduced survival of young salmon in freshwater. The primary estimator of numbers of sockeye returns is based on the number of parent spawners four years earlier, because most sockeye return to their natal river at age four, after spending two years at sea and two years in freshwater. On this basis, the prediction for 2012 returns is 0.7 million to 7 million, at the 10% to 90% probability distribution. These numbers are lower than average, due to fewer spawning sockeye in 2008. Fraser River sockeye returns in 2013 might be lower than average as well, due to fewer parent spawners in 2009, combined with generally favourable conditions in the Strait of Georgia in 2011, noted previously (Grant).

1.1.6 Pink Shrimp and Eulachon Biomasses Decline, Groundfish Increase While Herring Variable with Continued Declines in Size at Age

Other biological findings in 2011 include decreased pink shrimp biomass west of Vancouver Island from higher values in 2009 and 2010, likely as a result of warmer waters in spring two years previously when the shrimp were young. The mean trophic level of the commercial fisheries catch off the west coast of Vancouver Island has been increasing since 1980, whereas the mean trophic level of the fish community as determined by fishery-independent surveys, during the annual assessment of pink shrimp, shows no significant trend since 1980; this indicates no evidence for 'fishing down the food web' in this ecosystem (Perry et al.). Biomass indices for most groundfish species in Hecate Strait and Queen Charlotte Sound are trending upwards after several years of decline (Workman and Rutherford).

Eulachon populations coast-wide are at low levels (Schweigert et al.) while Pacific sardine biomass increased in 2011 compared to 2010 (Flostrand et al.). Herring biomass forecasts for Haida Gwaii and Central Coast stocks are below fishery thresholds, while for the Strait of Georgia and Prince Rupert stocks, biomass forecasts are above fishery thresholds (Boldt et al.). Length-at-age and weight-at-age of post-recruit herring has decreased in all BC populations since the 1970s (Boldt et al.; Hay et al.), including herring populations not fished during the herring roe fishery. Similar changes have occurred in California and some, but not all SE Alaska herring populations.

As herring size-at-age has decreased, the relative proportion of gonad sizes has increased, so the implication is that in recent years, herring expend more energy on gonad growth (or reproduction) and less on somatic growth (Hay et al.). Because size-at-age has decreased in areas not fished, this decrease is not believed to be attributed to fishing.

1.1.7 West Coast Marine Birds do well, While Intertidal Bivalves Stable

Birds can be effective indicators of the state of marine ecosystems because they their large breeding aggregations can be relatively easily counted. Breeding success of Triangle Island Cassin's Auklets is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*. Breeding success in 2011 was better than the long-term average and well above that of 2010 (Hipfner).

Off the WCVI (Pacific Rim National Park Reserve), 2011 seabird abundance remained high and similar to 2010. Most species displayed stable or improving population trends over the past 4-5 years (Zharikov et al.).

Intertidal bivalve population abundances in Barkley Sound were about average relative to previous years. Manila clams continue to decline while there appears to be no spatial displacement of this species by the recently introduced varnish clams. SARA-listed Olympia oyster has displayed a recovering trend for the past 7 years but the numbers are still below those observed in late 1990s (Zharikov et al.).

1.1.8 Bottom up Processes Important in Strait of Georgia

An Ecopath with Ecosim (EwE) model suggests that abundance changes for lingcod, killer whales, harbour seals and dogfish are mostly influenced by fisheries, a top-down mechanism. Other groups like coho salmon, Chinook salmon and herring responded to bottom-up forcing. Simulated changes in primary production by EwE were highly correlated with changes in spring and summer wind speeds, suggesting a possible link between this ecosystem and climate variation (Preikshot and Perry). Although zooplankton in the Strait of Georgia showed strong multi-year fluctuations, data suggest a partial recovery from low copepod and euphausiid biomass levels in the 2000s (Mackas et al.).

1.1.9 Contaminants

Persistent, bioaccumulative and toxic (P-B-T) contaminants present a health risk to aquatic biota, notably those at the top of food webs. Recent analyses of biopsy samples taken from young harbour seals live-captured at Gertrude Island (Washington, USA) in the Salish Sea reveal that polychlorinated biphenyls (PCBs) declined by 81% between 1984 and 2009 (Ross) This trend coincides with declining PCB concentration in bottom sediments of the Strait of Georgia in recent years. The decline in seal PCB concentrations reveals a substantial reduction in the health risks associated with endocrine-disrupting contaminants. Mammals near Gertrude Island had previously been identified as having higher PCB concentrations than at several other sites in the Salish Sea (Ross).

In contrast to the reduction in PCB-related risks, however, the concentration of polybrominated diphenyl ethers (PBDEs) increased in harbour seals sampled at Gertrude Island from 1984 to 2003, with some decline since then. The emergence of the PBDEs as a concern is consistent with observations elsewhere in the Salish Sea, but the surprisingly high PBDE to PCB ratios in seals suggests that there exist important local sources of this flame retardant. Recent studies of sediments and waste water effluent suggest that municipal waste water has delivered large quantities of PBDEs to the Strait of Georgia. The suggestion of a peak in PBDE levels in seals followed by a decline is consistent with the 2004 phase-out of two of the three PBDE products in Canada and the USA. This may be substantiated by future measurements (Ross).

1.1.10 Oil on British Columbia Waters

Airborne surveys for oil on British Columbia waters have operated with increased efficiency since 2006, when more accurate sensors were added to the surveillance aircraft flights by Transport Canada, as part of the National Aerial Surveillance Program. Observations by this program, together with modelling and analyses of these observations from 2006 to 2010 by the Canadian Wildlife Service, reveal several regions of British Columbia waters have higher likelihood of receiving oil from vessels through operational discharges, which includes accidental spills and intentional illegal discharges. The highest relative likelihood of detecting oil discharges occurred close to shore and, in particular, in the Strait of Georgia, the inside passage of the central coast, near Prince Rupert, and in Alberni Inlet. Although results are preliminary, results suggest that marina densities and intensity of local vessel activity (as opposed to international shipping) generally determine oil discharge patterns in the Pacific Region. There is some evidence that oil discharges have declined since the program was enhanced in 2006 (O'Hara).

1.1.11 Oxygen Concentrations in Coastal Waters

Scientists have reported alarmingly low oxygen concentrations in near-shore waters of the Oregon coast in summer, beginning in 2002 and most severely in 2006. High crab mortalities on the ocean bottom took place in these summers. Low oxygen concentration (less than 1 ml/L) has also been observed on the continental shelf of southwest Vancouver Island since 2002, with a concentration of 0.7 ml/L at 150 metres depth recorded in 2006 and 2009, the lowest in the 50 year record (Crawford and Peña). Concentration was 1.0 and 1.1 ml/L in 2010 and 2011, respectively. Although the frequency of observations of low oxygen concentration increased from 2002 to 2009, hypoxia on the Canadian shelf is much less severe than off Oregon and Washington, and mortality of bottom life has not been reported (Crawford and Peña).

1.1.12 Ocean Acidification

Deep water in the North Pacific Ocean already has among the most acidic water in the global ocean. pH is a commonly used measure of acidity, with low pH values indicating more acidic water. Summer upwelling off southwest Vancouver Island causes low-pH, intermediate-depth water from 100 to 200 metres below surface to come up into the ocean surface layer. The upwelled water is high in nutrients and DIC and so is lower in pH. However this DIC is quickly drawn down by primary producers (phytoplankton), and so the exposure of surface water on the shelf to low pH water is expected to be intermittent (Ianson). To date there have been no *in situ* studies of the effect of this exposure on the local organisms

There are no complimentary winter observations at present, although because of colder surface temperatures, winter mixing, higher DIC and lower primary production, there may be corrosive surface water over the shelf at this time of year. Given the lack of winter observations, scientists rely on model simulations of present-day pH on the continental shelf of southwest Vancouver Island. The model indicates that pH is lower (acidity is greater) in the upper mixed layer in winter than in summer. pH is lower near the bottom of the continental shelf and slope than found in the upper mixed layer throughout the year (Ianson).

1.1.13 Ecosystem Indicators: What are they, and Who is asking for them?

Fisheries and Oceans Canada (DFO) is moving towards an ecosystem-based approach to management (EAM) of human activities in Canada's aquatic environments. The State of the Pacific Ocean workshop is a good venue to review some of these Ecosystem Indicators.

EAM will require science to develop a new suite of tools and products to advise resource managers on the impact and management options for human activities in the marine environment. The three key pillars that need to be considered in the developing an EAM are Biodiversity, Habitat and Ecosystem Structure, and Function. Ecosystem indicators are derived to evaluate ecosystem status in support of EAM and to assess effects on the ecosystem of stressors associated with human activities (Boutillier et al.). Subsequent State of Ocean workshops are expected to report on the continued development of ecosystem indicators.

2 APPENDIX 1 INDIVIDUAL REPORTS

2.1 GENERAL/GULF OF ALASKA

2.1.1 Temperatures in 2011: Globally warm, but cool in the Eastern Pacific

Bill Crawford, Fisheries & Oceans Canada

Global temperature anomaly and its change since 1880

The global surface temperature in 2011 was warmer than average almost everywhere, but not in the eastern Pacific Ocean. Fig. 1 shows the extent to which temperature was warmer (red) or cooler (blue) in 2011 compared to the reference period of 1971 to 2001. Local cooling in the eastern Pacific Ocean has been present in almost every year since 2008, part of a Pacific-wide weather pattern associated with La Niña conditions of these years. This pattern of cool ocean surface water was interrupted only briefly in the winter of 2010, when El Niño winds brought warmer waters to this region.

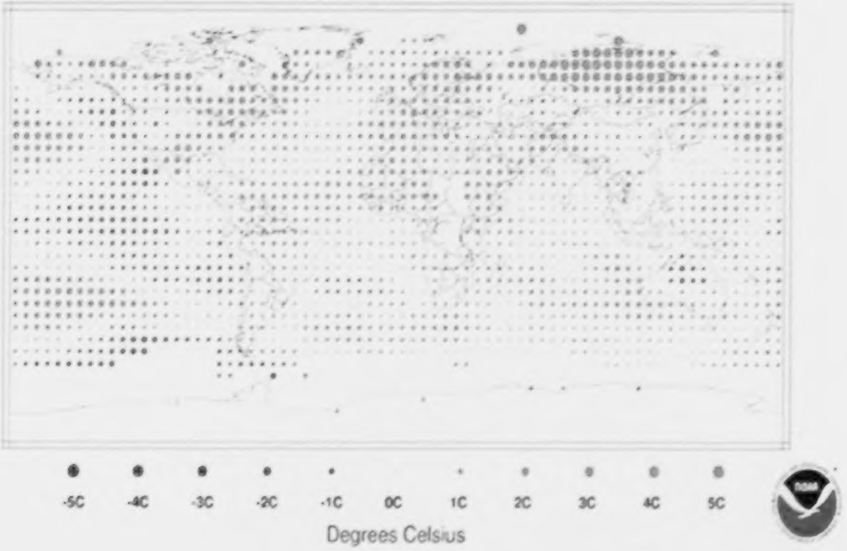


Figure 1. Annual surface temperature anomaly for 2011 (°C). relative to 1971 to 2000. Image provided by the National Climate Data Center of NOAA of the US National Oceanic and Atmospheric Administration.

The long-term global temperature trends are shown in Fig. 2 for the total surface of the earth (land and ocean) and also for the ocean only. Both graphs below show that temperature in 2011 was cooler than typical temperatures since 1997, but warmer than temperatures prior to 1977.

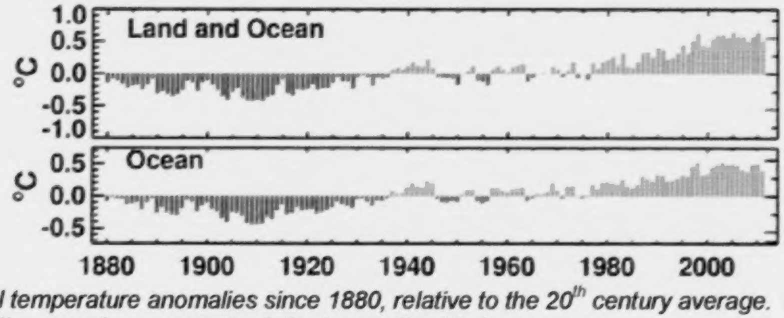


Figure 2. Global temperature anomalies since 1880, relative to the 20th century average. Image provided by NOAA: http://www.ncdc.noaa.gov/cmb-faq/anomalies.html.

El Niño and La Niña dominate ocean temperature in the eastern Pacific Ocean

The prevailing weather pattern over the Gulf of Alaska in winter determines our ocean surface temperature through much of the year. Fig. 3 below shows the average air pressure at sea level in each of the four past winters, including January to March of 2012. The letter **L** marks the centre of the Aleutian Low Pressure System that forms every winter. When it is larger than normal in area and its central air pressure is relatively low compared to other winters (for example in 2010 in Fig. 3b), the winds along the west coast blow more strongly from the southeast, bringing warm air and warm ocean-surface water toward the BC coast. This wind direction is shown by the black arrow in Fig. 3b. This winter pattern is more frequent in El Niño winters, and El Niño did indeed take place in this winter.

The winters of 2009, 2011 and 2012, illustrated below, show a very different weather pattern. In these winters the North Pacific High Pressure System, labelled **H**, covered a large area, and its central air pressure was higher than normal for winter. The prevailing winds of any single winter tend to flow along isobars (lines of constant air pressure), and flowed more from the west than in winter 2010, bringing cool air and ocean water to the BC coast. This wind direction is shown by black arrows in Fig. 3a, 3c and 3d. This pattern is more frequent in La Niña winters. Both 2011 and 2012 were La Niña winters, and conditions in 2008 were close to those of La Niña.

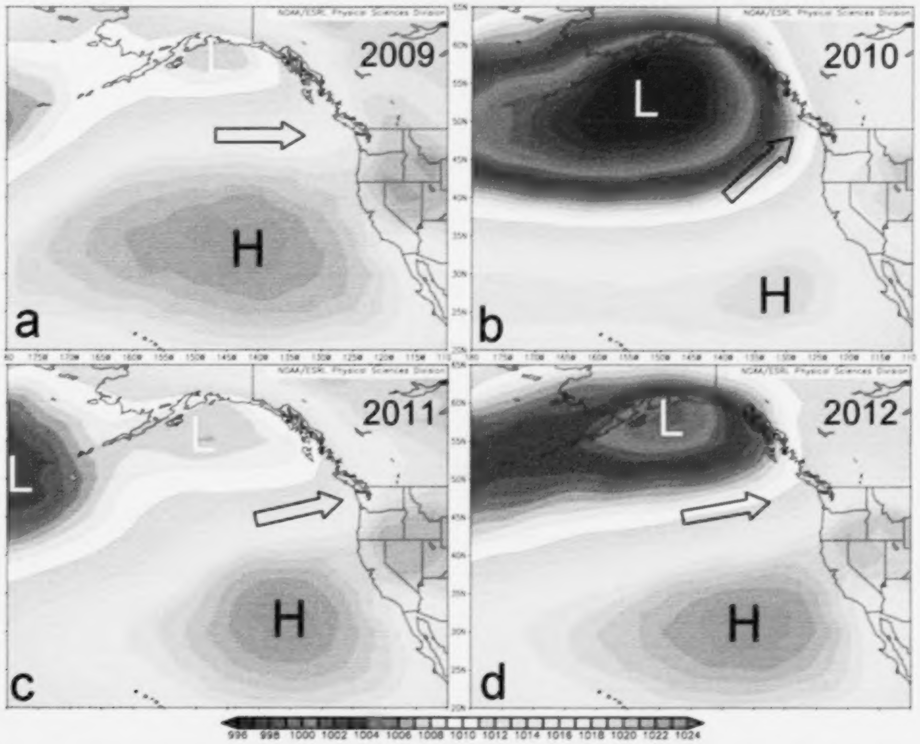
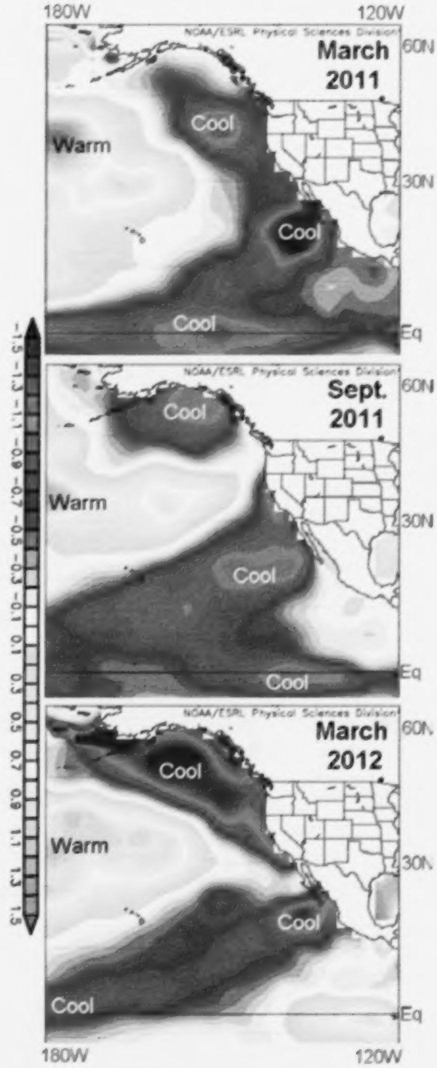


Figure 3. ***Sea surface air pressure*** *in the Northeast Pacific Ocean and western North America, averaged over the winter months of January to March for each of the years 2009 to 2012. Contours are at intervals of 1 millibar, with colour scale at bottom. The letter* **H** *denotes the North Pacific High Pressure System;* **L** *denotes the Aleutian Low Pressure System. Figures are provided on-line by this NOAA Internet site: http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl*

The recent anomalies of ocean temperature in the eastern Pacific Ocean can be seen in the three panels of Fig. 4. These maps present temperature anomalies of March and September 2011 and March 2012.

Figure 4. ***Ocean surface temperature anomaly*** *in the eastern Pacific Ocean for March 2011 (top), September 2011 (middle), and March 2012 (bottom). The maps extend from North America west to 180°W, and from 5° South to 65° North. The equator is marked by the horizontal black line near bottom of each panel. The temperature anomaly scale in °C is at left. Positive and negative temperature anomalies are labelled warm and cool, respectively in each panel. Reference years for temperature anomaly are 1981 to 2010. Images provided by NOAA: http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl*



All three panels of Fig. 4 show cool ocean surface waters off the west coast, and also on the Pacific Equator. These conditions have prevailed for four of the past five winters and only in the winter of 2010 were ocean temperatures warmer than normal off the west coast.

All four of these winters with cool ocean temperature are associated with La Niña events, or La Niña – type events on the Pacific equator. La Niña occurs when ocean temperature in mid-Pacific along the equator is more than 0.5 °C below normal for six to seven months; El Niño when temperature is more than 0.5 °C above normal. These cool ocean temperatures on the equator and also along the west coast are usually set up by stronger northeast trade winds over the tropical Pacific Ocean and stronger westerly winds in the eastern North Pacific.

The link between ENSO events (a term that includes both El Niño and La Niña) and winds and ocean temperatures off western North America was noticed several decades ago, and has become stronger in the past 10 years or so, allowing more reliable predictions in winter weather based on the ENSO cycles. La Niña of the winter of 2012 was fading in early April 2012, and was expected to disappear by month-end.

The study of the atmosphere-ocean links extending across the Pacific-wide can help interpret warm and cool conditions, such as the recent cool ocean temperatures west of Canada and northern USA. Time series of many of these patterns are presented next.

Linking Pacific-wide climate variations to local temperature

How will El Niño affect the weather this year? What happens in the North Pacific Ocean to bring a cool winter? Or a warm summer? To try to answer these questions in a simple manner, scientists look at ocean temperature and/or air pressure in specific regions of the Pacific Ocean to develop indices whose changes in time will impact other areas far away. El Niño is the most famous, the Southern Oscillation is another. Time series of five of these Pacific – wide indices are presented in Fig. 5, together with one graph of local ocean temperature anomaly at Amphitrite Point on southwest Vancouver Island and another of ocean temperature anomaly in eastern the Gulf of Alaska (Line P at 10 to 50 m depth). In general, blue for each index aligns with a cool ocean at Amphitrite Point and along Line P and red with warm ocean temperature.

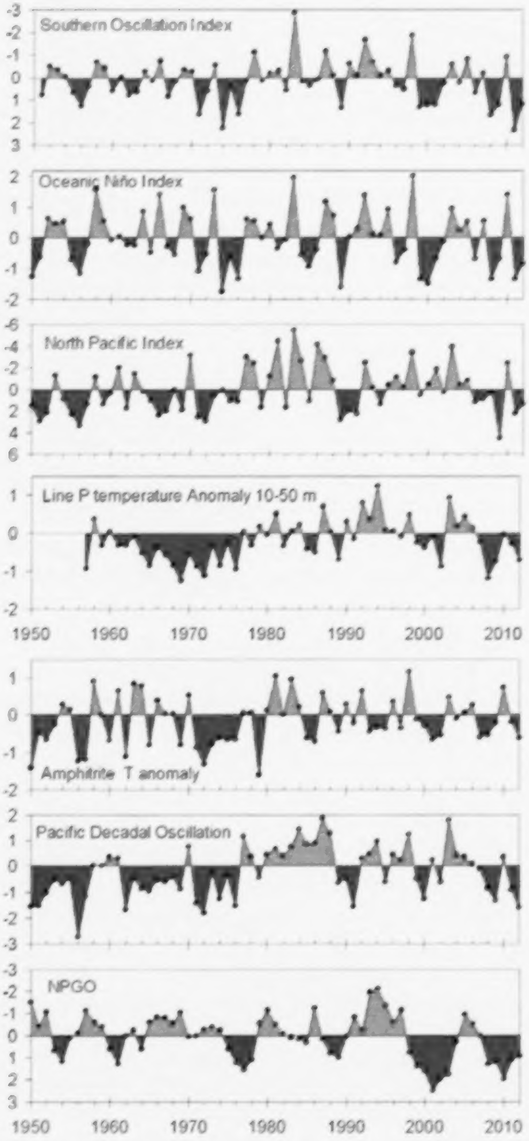


Figure 5. Four indices of Pacific Ocean winter climate, plus temperature anomaly (°C) of the Oceanic Niño Index and at Amphitrite Point and along Line P. Each point is an average over the months of November to March, and plotted for the calendar year of March. For example, an average of November 2011 to March 2012 is plotted as a data point for 2012. Several time series are inverted so their variability is in phase with other series. Some indices for 2012 do not include February or March 2012 conditions.

It is remarkable how all of the series of Fig. 5 are blue over the past two winters, and are mainly blue over the past six winters. Only for the winter of 2010 are there any red values in these seven graphs.

The time series at top of Fig. 5 presents the Southern Oscillation Index (SOI), which represents the strength of the trade winds in the tropical Pacific Ocean, which in turn set up ENSO. For example, a positive SOI in 2012 (blue in top panel of Fig. 5) coincided with stronger trade winds, which brought cooler waters to the mid-Pacific Equator and La Niña (negative Oceanic Niño Index in Fig 5). Stronger trade winds coincided with stronger westerly winds in the North Pacific Ocean, which created cooler waters in the eastern Gulf of Alaska (negative anomaly along Line P in Fig. 5) and along the west coast of Canada and USA (negative anomaly at Amphitrite Point on the SW coast of Vancouver Island, Fig. 5). All these graphs are coloured blue in 2012.

All of the time series in Fig. 5 are explained in the next paragraph. Here, I note their common variability. In general, blue regions prevailed prior to 1977, and red regions after then for about two decades until 1998. The Pacific Decadal Oscillation (PDO) shows this pattern the best. Most time series shift from red to blue in the late 1990s and again the late 2000s. An exception is the North Pacific Index (NPI) which remained negative (red) through most years from late 1970s through to the mid 2000s. Note the extreme cooling along Line P since 2007. In general, cooling aligns with La Niña (negative ONI), negative PDO, NPGO and NPI, and positive Southern Oscillation Index. Details of these time series listed next.

Amphitrite temperature anomaly time series is based ocean surface temperature measured daily at the Amphitrite Lighthouse on the southwest coast of Vancouver Island. Reference years are 1981 to 2010. Monthly time series are provided by Fisheries and Oceans Canada: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm

Oceanic Niño Index (ONI) is a measure of the anomaly of ocean surface temperature in the central tropical Pacific Ocean, and serves as the official index of the El Niño and La Niña. It is provided by the NOAA/ National Weather Service National Centers for Environmental Prediction Climate Prediction Center, Camp Springs, Maryland: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Southern Oscillation Index is available at: http://www.cpc.ncep.noaa.gov/data/indices/soi. It represents the atmospheric pressure difference between Tahiti and Darwin, Australia, that usually sets up the El Niño and La Niña ocean responses. A strong pressure gradient and positive SOI (blue in Fig. 5) set up La Niña ocean conditions.

North Pacific Index (NPI) is the area-weighted sea level pressure over the North Pacific from 30°N to 65°N and 160°E to140°W. It serves as an index of the impact of ENSO over the North Pacific Ocean. Monthly time series of this index are provided by the Climate Analysis Section, NCAR, Boulder, USA, http://www.cgd.ucar.edu/cas/jhurrell/npindex.html based on Trenberth and Hurrell (1994). This index is a useful indicator of the intensity and areal extent of the Aleutian Low Pressure system. Both monthly and winter-only values are available.

Line P temperature anomaly is based on Crawford et al. (2007) and is updated annually. Line P is a set of sampling stations in the North Pacific sampled regularly by Fisheries and Oceans Canada since the 1950s. Reference years are 1981 to 2010. http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/line-p/index-eng.htm

Pacific Decadal Oscillation (PDO) is based on analysis of Mantua et al. (1997) and Zhang et al. (1997). It is the 1st mode of ocean surface temperature variability in the North Pacific Ocean, and is often positive in El Niño years. However, its year-to-year variability is slower than that of ONI, and it is usually a good indicator of weather patterns that persist for a decade or more. The time series was provided at this Internet site of the Joint Institute for Studies of Atmosphere and Ocean of NOAA in Seattle: http://jisao.washington.edu/pdo/PDO.latest

North Pacific Gyre Oscillation (NPGO) is a climate pattern that emerges as the 2nd dominant mode of sea surface height variability (2nd EOF SSH) in the Northeast Pacific Ocean. (Di Lorenzo et al; 2008) http://www.o3d.org/npgo/ When positive (blue in Fig. 5), the westerly winds over the eastern North Pacific are often stronger than normal and the west coast and eastern Gulf of Alaska are cool. These conditions have dominated in most winters since 1999.

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2.1.2 Ocean conditions in Gulf of Alaska

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Summary

Ocean surface temperature was cooler than normal near the BC coast in 2011, except for a brief warm period in late August west of Vancouver Island. The eastward flow in the North Pacific Current and northward flow in the Alaska Current both increased through 2011, but declined in early 2012. A layer of very salty water was observed near 150 metres depth through the eastern part of the Gulf of Alaska. In general, this layer has been saltier since 1976 than in the previous twenty years. Oxygen concentrations in open-ocean waters were higher in summer 2011 than in summer 2010 in the top 100 metres. The winter mixed layer in early 2012 was one of the deepest ever.

Temperature and salinity in surface waters

We assembled ocean observations by the Argo program and also by Fisheries and Oceans research cruises, and at lighthouses and weather buoys. Symbols in Fig. 1 represent individual measurements in the top 10 metres of the ocean, which we label "Near-Surface".

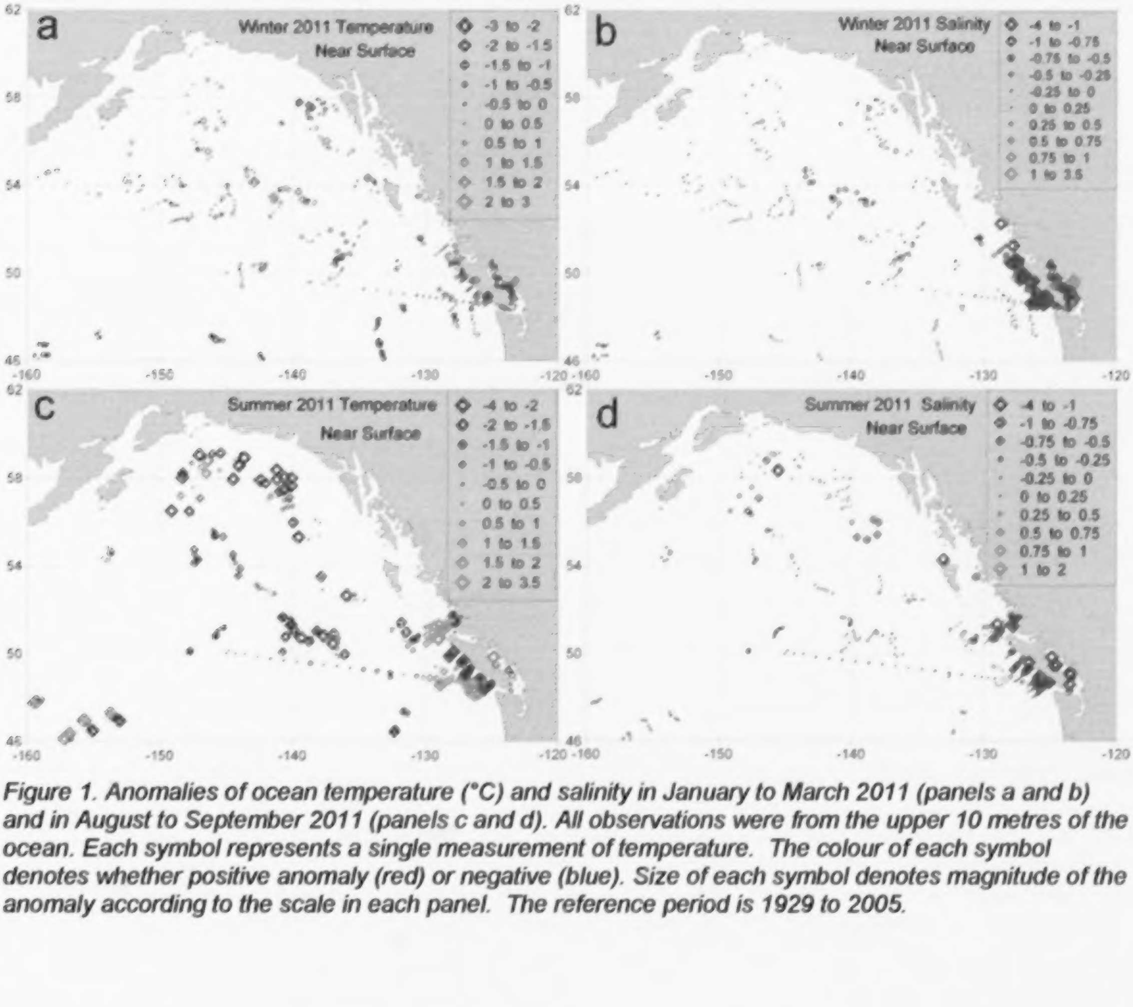
a
Winter 2011 Temperature
Near Surface
-3 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0
0 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 3
b
Winter 2011 Salinity
Near Surface
-4 to -1
-1 to -0.75
-0.75 to -0.5
-0.5 to -0.25
-0.25 to 0
0 to 0.25
0.25 to 0.5
0.5 to 0.75
0.75 to 1
1 to 3.5
c
Summer 2011 Temperature
Near Surface
-4 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0
0 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 3.5
d
Summer 2011 Salinity
Near Surface
-4 to -1
-1 to -0.75
-0.75 to -0.5
-0.5 to -0.25
-0.25 to 0
0 to 0.25
0.25 to 0.5
0.5 to 0.75
0.75 to 1
1 to 2
62
58
54
50
46
-160
-150
-140
-130
-120

Figure 1. Anomalies of ocean temperature (°C) and salinity in January to March 2011 (panels a and b) and in August to September 2011 (panels c and d). All observations were from the upper 10 metres of the ocean. Each symbol represents a single measurement of temperature. The colour of each symbol denotes whether positive anomaly (red) or negative (blue). Size of each symbol denotes magnitude of the anomaly according to the scale in each panel. The reference period is 1929 to 2005.

The ocean near British Columbia remained cool through January to March of 2011 (Fig. 1a), continuing the cool conditions from the previous winter. These cooler-than-normal waters remained into July, but in August a change in weather brought warmer-than-normal water to the north and west coast of Vancouver Island, as illustrated by the red symbols in Fig. 1c. This warming was short-lived, and the variable weather of August and September brought both warm and cool waters to these two regions throughout these two months, as shown by the presence of both red and blue symbols west of Vancouver Island in Fig. 1c.

A continuous record of daily measurements of ocean temperature through 2011 at four lighthouses is presented by Chandler 2012 (elsewhere in this research document), showing cool coastal ocean waters through the year in British Columbia, except for a few brief, warm periods in the summer.

Fresher-than-normal waters prevailed in both January to March and August to September 2011 near Vancouver Island (Fig. 1b and 1d), whereas anomalies were much weaker in the Gulf of Alaska. The freshening along the west coast of Vancouver Island in August to September 2011 is in contrast to saltier waters in June and July 2011, and through the summer of 2010.

Ocean Surface Currents

Argo is a global array of 3000 free-drifting, profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean. For a few of the floats, dissolved oxygen profiles are also available. The number of floats supplying profiles at 10-day intervals in the Gulf of Alaska is sufficient to provide dynamic heights and streamlines of ocean currents, as mapped below.

Fig. 4 contrasts the broad and diffuse North Pacific Current in January 2011 (right) with the narrow and intense current in June 2008 (left). It is this North Pacific Current that might deliver debris from the Japan tsunami of March 2011. The decrease in its speed in the NE Pacific Ocean since 2008 might retard the arrival of material to west coast beaches. A typical time to drift across the Pacific is 2 to 3 years, although objects floating high in the water can travel more quickly and arrive sooner.

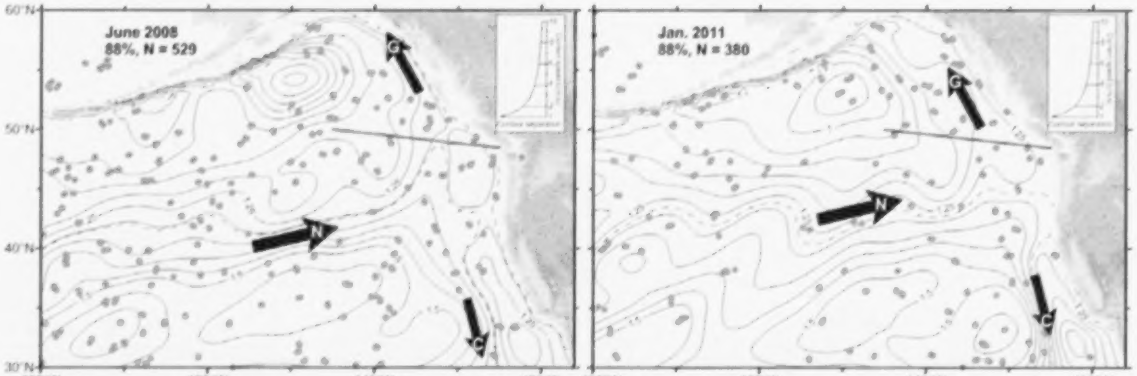

Figure 4: Two maps of the circulation of the NE Pacific. Streamlines of ocean surface currents are plotted in solid black lines. Closely spaced streamlines indicate stronger currents. The arrows labelled N, C and G identify the North Pacific, California and Alaska Currents, respectively. On the left is a map for June 2008 when the North Pacific Current was narrow and strong. Recently, as seen in January 2011, the North Pacific Current is broad. Red dots show positions of Argo floats that provided the information to prepare these monthly maps. The blue line is Line P, a set of ocean climate sampling stations. Labelled at top left are the number of Argo profiles contributing observations in the month, and a percentage measure of goodness of fit of these streamlines to observations.

Fig. 5 shows a time series of the strengths of the three major currents, and the ratio in red showing the fraction of water in the North Pacific Current that eventually heads northward in the Alaska Current into the Gulf of Alaska. Between 2004 and 2008 the amount of water carried in the North Pacific Current steadily increased, but it decreased from mid-2008 until the beginning of 2011.

When the Japanese tsunami occurred in March 2011, the North Pacific Current was almost as weak as we have seen it in the past 10 years. During 2011 there was a brief increase in the strength of the eastward flow towards British Columbia in the NE Pacific Ocean, but as of early 2012, the flow has reverted to the very weak phase and this is shown by the black line in Fig. 5. Of the water that does flow across the Northeast Pacific Ocean, part flows northwards into the Alaskan Stream and part southwards into the California Current. The red line in Fig. 5 shows the fraction of water in the North Pacific Current that heads into the Alaskan Stream; we see that this is somewhat below normal. This might tend to increase the probability that objects set adrift by the Japanese tsunami will eventually head southwards along the US coast, if they float low in the water. Objects floating higher, such as boats and plastic bottles, will be carried farther to the north in winter due to northward-blowing winds along the west coast. The earliest known arrival was a fishing trawler discovered in March 2011 west of Haida Gwaii. It drifted northward along the coast toward Alaska, and was eventually sunk by the US Coast Guard.

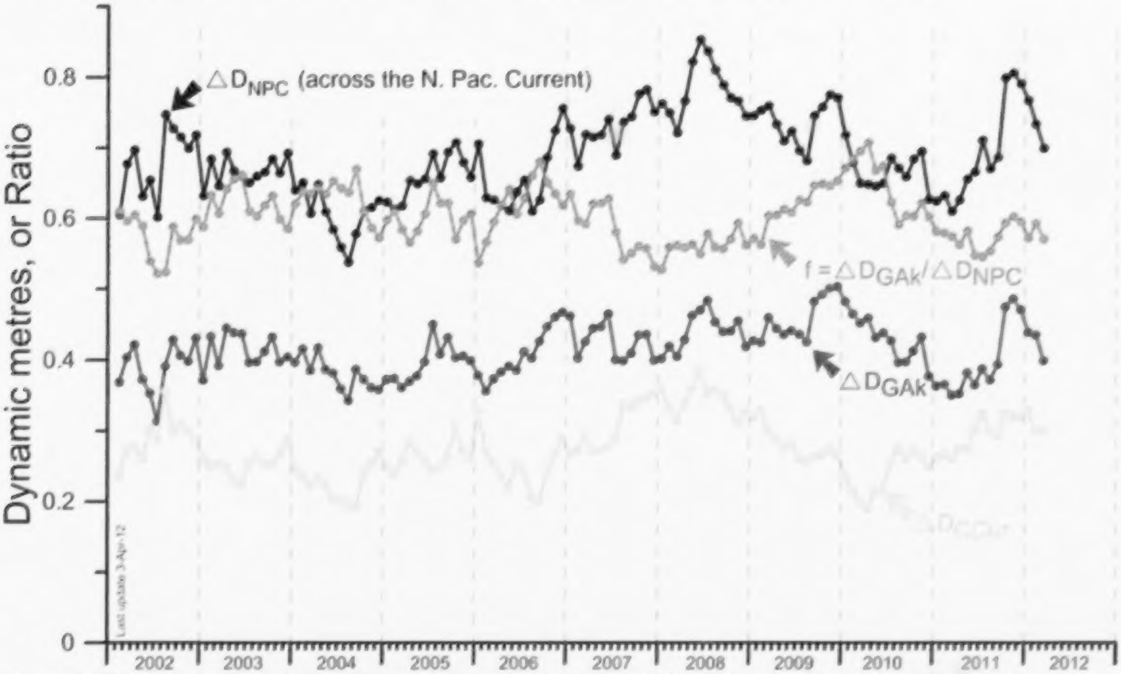

Figure 5. The difference in height between two streamlines in Figure 4 is a good surrogate for the strength of the current parallel to each streamline. The black, blue and green lines indicate the relative strength of flow in the North Pacific, Alaska and California Currents, respectively. Their pathways are shown in Fig. 4. The red line is the ratio of the blue line divided by the black line and so represents the fraction of North Pacific Current water that flows northward in the Alaska Current. The remaining water is carried to the south in the California Current.

Subsurface Ocean Features

We next show details of how these anomalies extended to offshore waters in the Gulf of Alaska along Line P, illustrated in Fig. 6

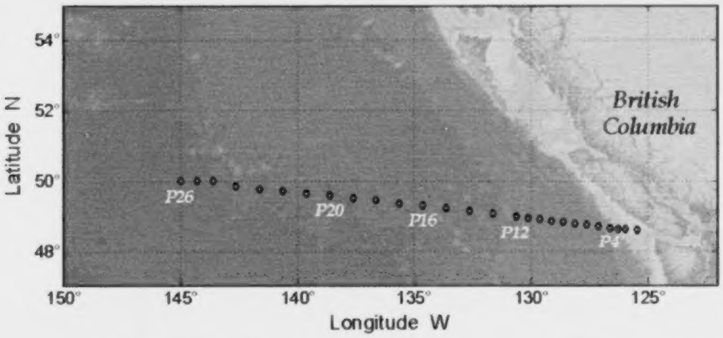

Figure 6. Line P stations in the Gulf of Alaska. Ocean Station Papa is at P26. Although all stations are sampled, more extensive water samples are collected and analysed at the numbered stations.

Following cool temperature in 2008 and 2009, in February 2010 these waters were above seasonal average temperature near the coast and in the top 100 metres (decibars). But during the following year the waters in the Gulf of Alaska returned to below-average temperature. During all three cruises of 2011, the waters along Line P were in general colder than the long term average of1956 to1991, as can be seen by the blue colour in Fig. 7. Only in late August at the ocean surface was there was a significant warming.

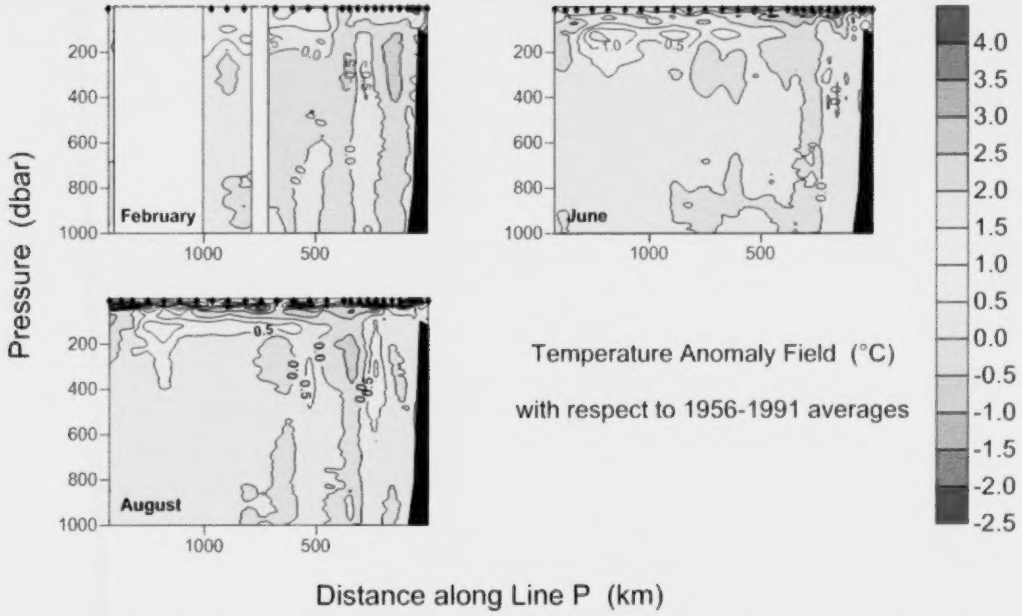

Figure 7: Temperature anomaly (°C) along Line P during three cruises in 2011. Pressure in decibars closely matches depth in metres.

Figs. 1b and 1d shows that the salinity anomaly near the surface of the Gulf of Alaska was weak during 2011 with a freshening near the coast of Vancouver Island. This pattern can also be seen along Line P. Fig. 8 shows the salinity anomaly for all three cruises of 2011 with respect to the long-term average. The only significant anomalies are the saltier waters in the near 150 metres depth (150 decibars) and the very fresh waters near the coast, especially in February. This salty layer at 150 metres was first observed on Line P in June 2010 (Robert et al. 2011), but its wide extent along Line P was not observed until 2011. Its cause is under investigation.

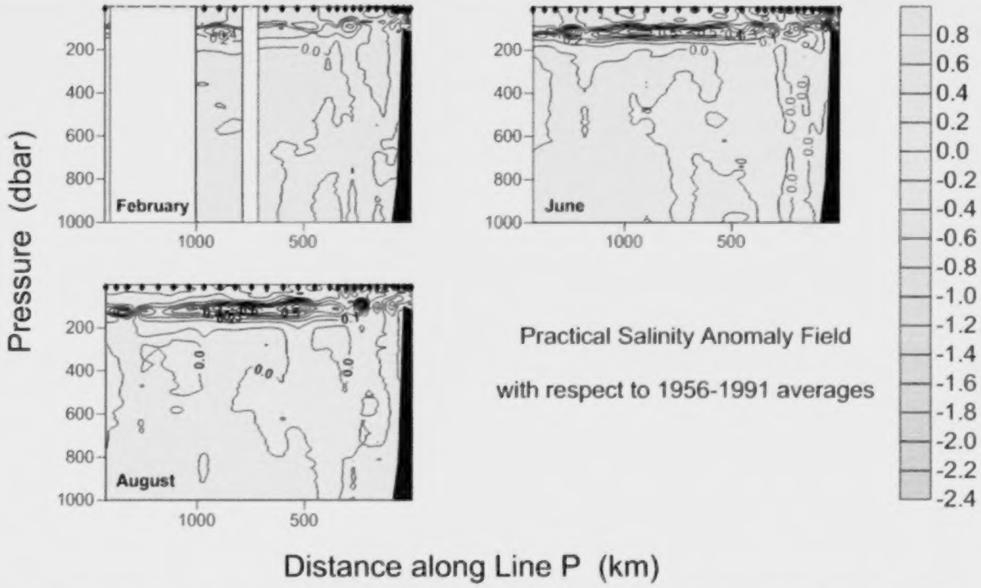

Figure 8: Salinity anomaly along Line P during three 2011 cruises. Pressure in decibars closely matches depth in metres.

Ocean density is measured by sigma-t, which is the density of seawater in kg/m^3, minus 1000. As can be expected, the sigma-t graphs reflect both the positive salinity anomalies down to 200m and the surface positive temperature anomalies (Fig. 9).

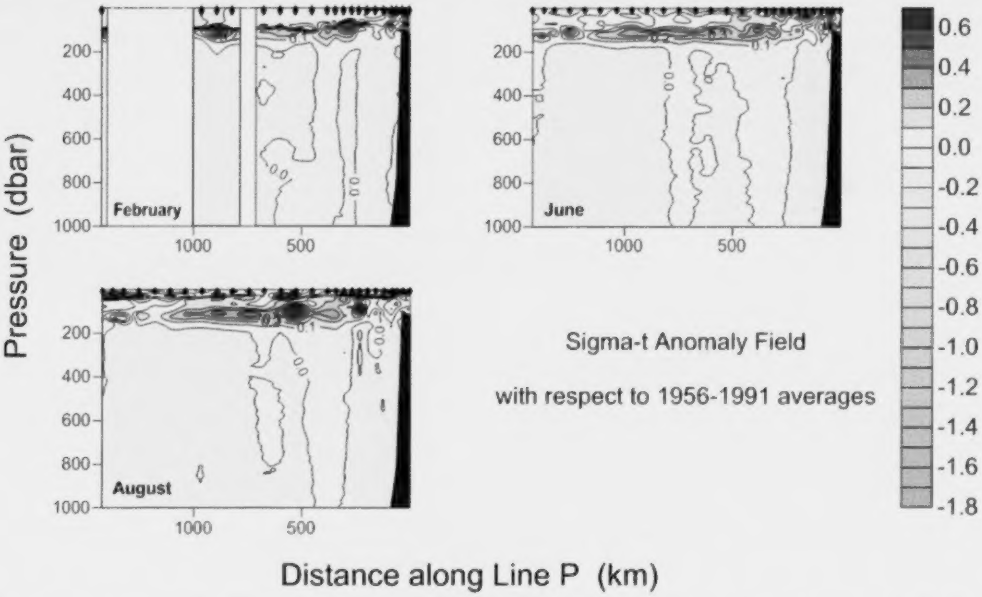

Figure 9: Sigma-t anomaly (kg/m^{-3}) along Line P during three 2011 cruises. The pressure in decibars closely matches depth in metres.

The dissolved oxygen values along Line P were different in 2011 than 2010, especially during the summer cruises. February 2011 saw a little more dissolved oxygen in the coastal waters than during the previous year, with the 6.5 ml/Litre contour reaching the shore (see Fig. 10, orange line). The 7.0 ml/Litre contour (red line) was present in June of both years, but it was present along most of Line P only in 2011, whereas only the middle 500 km or so of Line P had these values in 2010. The biggest difference was between August 2010 and August 2011. Values over 7.0 ml/l were found along most of Line P in 2011, whereas the dissolved oxygen remained below 7.0 ml/Litre in 2010, and even the 6.0 ml/Litre contour is not continuous along Line P.

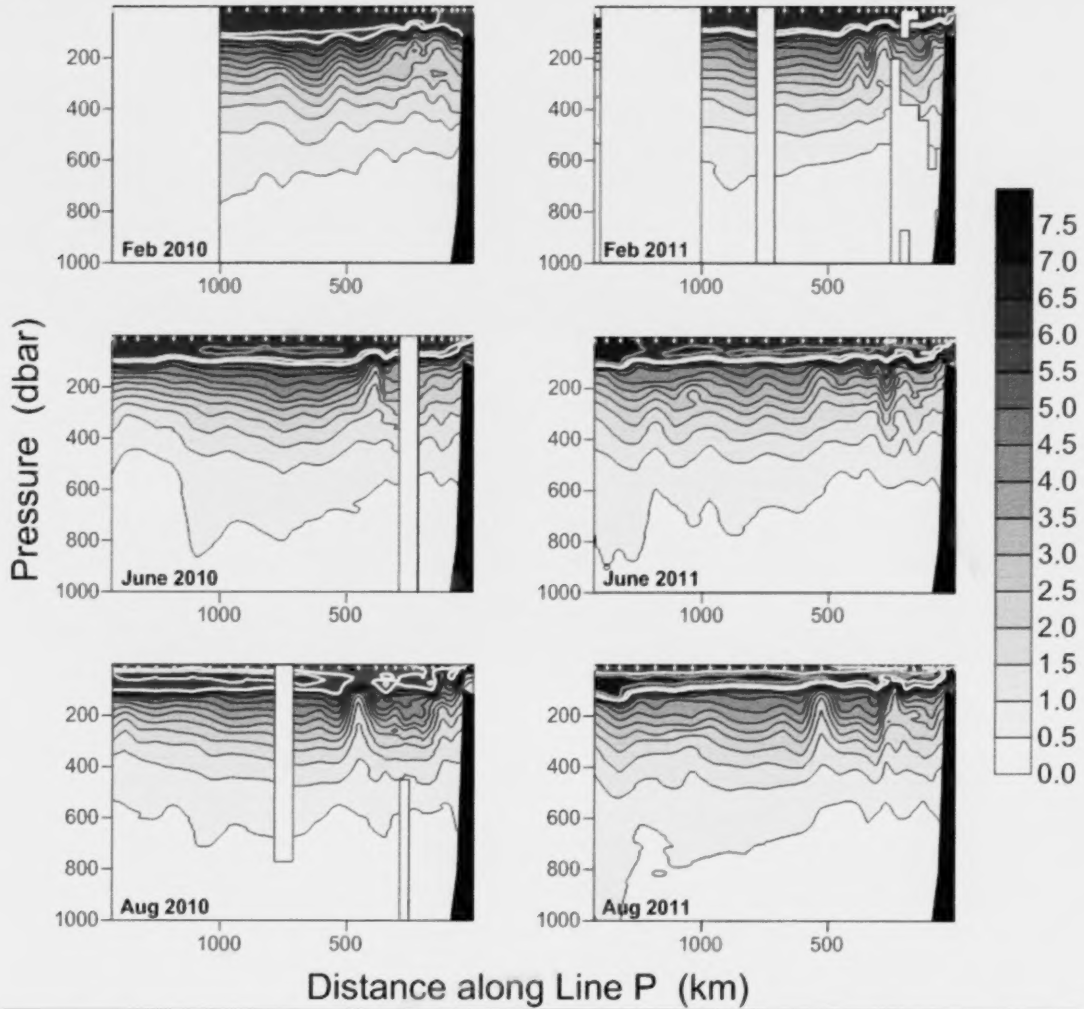

Figure 10: Dissolved oxygen along Line P during the three cruises of 2010 (left panel) and 2011 (right panel). The light yellow line indicates the 6.0 ml/litre contour; the orange contour represents 6.5 ml/litre, whereas the red line indicates concentrations of 7.0 ml/litre.

The year 2012 started fairly stormy. Only about half of the stations along Line P were visited during the February 2012 cruise. The temperature anomaly, salinity anomaly and sigma-t anomaly profiles, all with respect to the 1956-1991 average, as well as the dissolved oxygen profile for this cruise can be found in Fig. 11. No extreme anomalies were present; the most important features were the really fresh water inshore, near the coast of Vancouver Island (right-hand side of each graph). The main feature of this figure is the very low level of dissolved oxygen near the surface when compared to the February data of the previous two years, and also compared of high concentrations in August 2011 (Fig. 10). Note that the February 2012 data are presently in final quality control and results might change slightly.

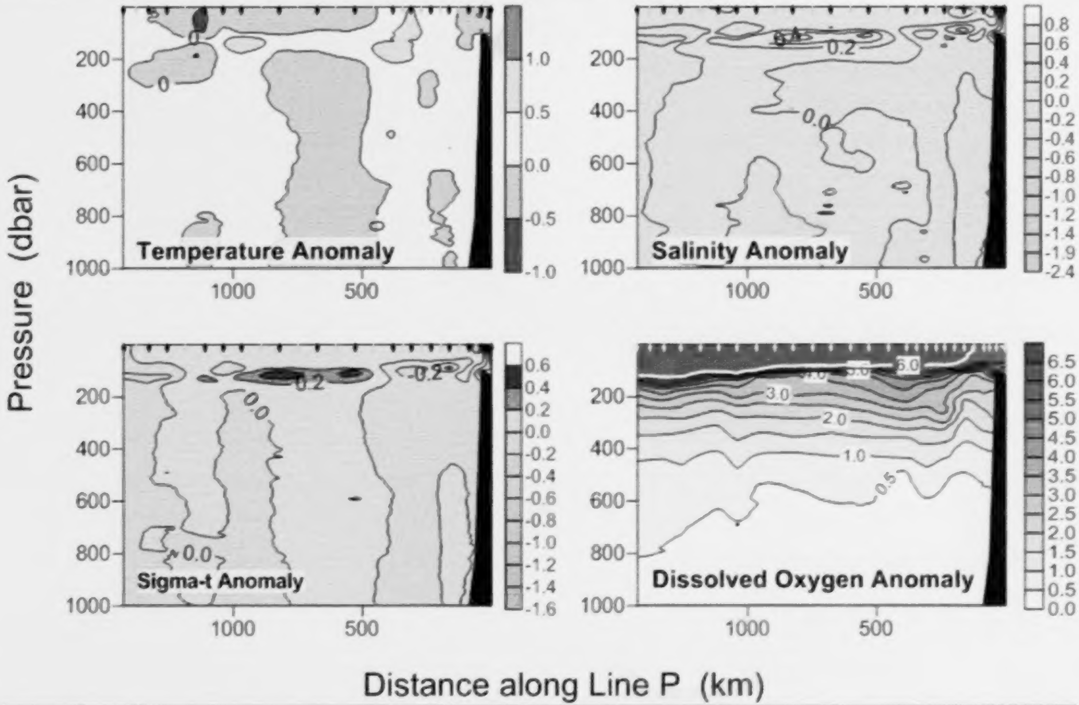

Figure 11: Anomalies of temperature, salinity and sigma-t in February 2012 with respect to the 1956-1991 average, as well as dissolved oxygen along Line P. The black and orange markers along the upper horizontal axis of each graph indicate sampling stations. The light grey markers indicate missed stations. The light yellow line on the dissolved oxygen graph shows the 6.0 ml/litre contour.

56 years of temperature and salinity change along Line P.

The images above show changes in water properties over the past 15 months. With more than 50 years of regular observations along Line P we can show how present conditions compare to the ocean climate of the past decades (Fig. 12).

The graphs in Fig. 12 show changes in ocean temperature along Line P over the past 56 years, based on the regular sampling during these years and supplemented with observations at nearby stations by Argo profilers and other sampling programs. The anomalous temperature and salinity of each observation were determined by comparing to the climatological average of that week and depth and position along Line P based on sampling from 1981 to 2010. Each panel presents contours of temperature or salinity anomalies over near-surface waters and deeper waters. Blue regions denote negative anomalies and relatively cool or fresh waters whereas red regions show positive anomalies and relatively warm or salty water.

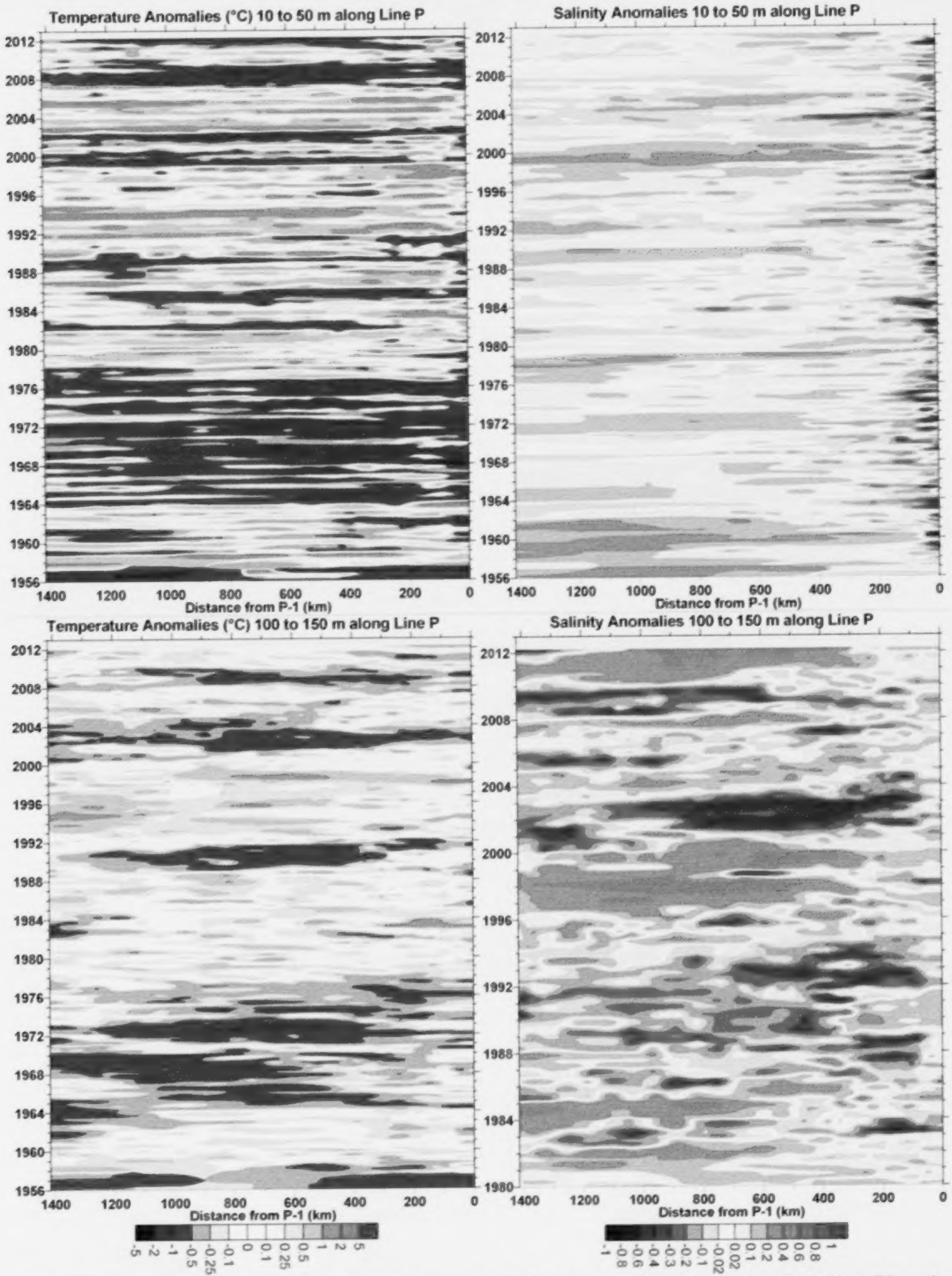

Figure 12. Time-distance plot of temperature (°C) and salinity anomalies along Line P at 10 to 50 metres depth (top) and 100 to 150 metres depth (bottom). Anomaly scales are at bottom. Ocean Station Papa is at far left in each panel. Reference years are 1981 to 2010. Update of figures in Crawford et al. (2007).

Note the intense cooling along Line P from 2007 to 2008 along all of Line P, and for almost all of the years 2008 to 2011. Only in the 1960s and 1970s were such negative temperature anomalies found to persist for several years. Warmer water appeared midway along Line P in late 2009 and stayed until 2010; however by late 2011 all of Line P near surface was relatively cool. The shifts in temperature from late 1990s to present have generally followed the El Niño – La Niña cycles, with warm ocean waters associated with El Niño and cool waters with La Niña.

The ocean salinity varies little in the top 100 metres along the deep-sea region of Line P, but increases sharply from 110 metres to 150 metres. If these deep waters upwell, the salinity at 100 to 150 metres increases sharply. For this reason the variability in salinity is greater at 100 to 150 metres depth (Fig. 13, right) than at 10 to 50 metres (Fig. 13, left). Since the mid-1990s the salinity anomalies from 100 to 150 metres depth have been greater than in previous decades. Most of Line P in 2010 to 2012 was saltier than normal at these depths, as noted previously in Figs. 8 and 11. Unlike changes in temperature, the salinity anomalies do not respond reliably to changes in the El Niño – La Niña cycle, nor to the Pacific Decadal Oscillation. Di Lorenzo *et al.* (2010) suggest that the North Pacific Gyre Oscillation and strength of the North Pacific Current are reasonable indicators of salinity changes at Ocean Station Papa, and of changes in surface nitrate all along Line P.

Mixed Layer Depth at Ocean Station P

The number of Argo floats supplying profiles at 10-day intervals in the Gulf of Alaska is sufficient to provide continuous information at Ocean Station Papa at 50°N, 145°W. A contour plot of water density anomaly, specifically sigma-t (σ_t) (defined as water density in kg m^{-3}, minus 1000) is shown below.

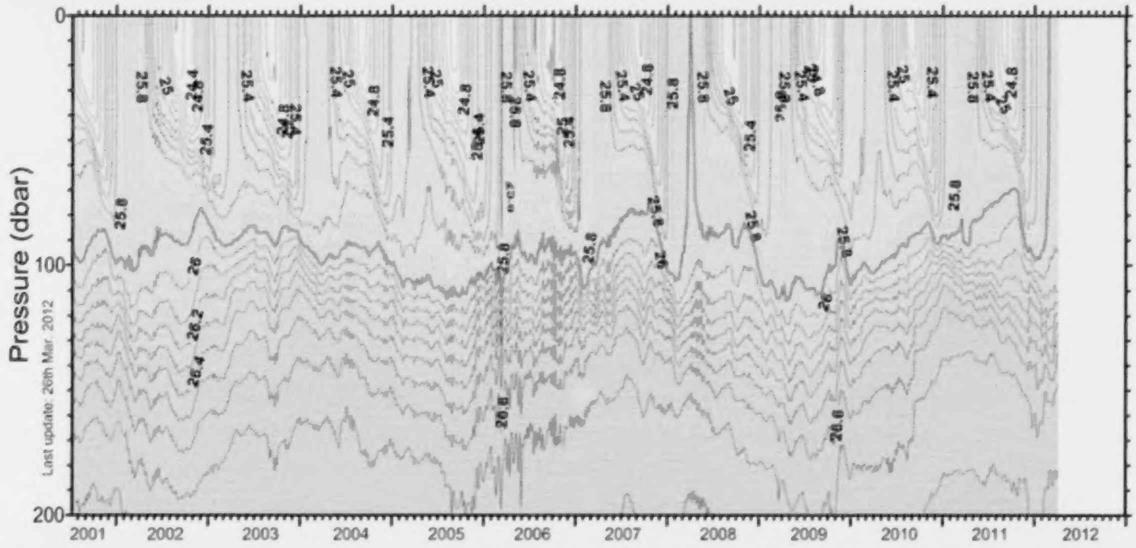

Figure 13. A plot versus time on the x-axis and water pressure on the y axis of density anomaly (σ_t) at Ocean Station Papa. The green contour marks a σ_t of 25.8 and the red line a σ_t of 25.9. (water densities of 1025.8 and 1025.9 kg/m^3, respectively). Pressures in decibars (dbar) approximate depths in metres..

Fig. 13 shows a plot of density at Ocean Station Papa, a well-studied location in the Gulf of Alaska. Two density contours are highlighted just to show how variable winters can be. As wind-driven mixing gets progressively deeper, usually in late winter, seawater surfaces of higher density are brought to the sea surface. Looking at the green line representing a density of 1025.8 kg/m^3, we see that mixing is deep enough to raise it to the sea surface in about half of all winters. The slightly denser surface of 1025.9 kg/m^3 however is rarely brought to the surface.

Before the winter of 2011/12 we had only once previously seen this density reach the sea surface and that was a very brief event. However, late in the winter of 2011/12 we are seeing the deepest penetration of the mixed layer that has been observed in the last decade in the Gulf of Alaska.

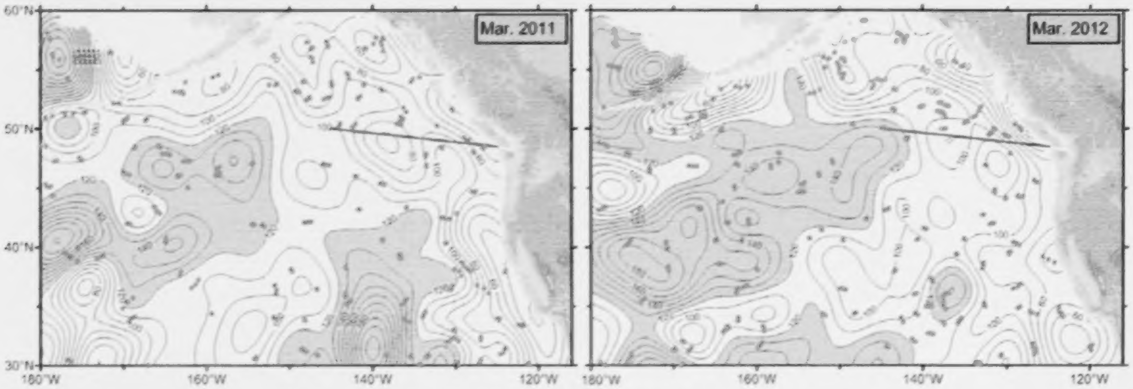

Figure 14. The depth of the surface mixed layer in March 2011 and March 2012. The areas of the ocean where mixing penetrates to 120 metres or more are shaded grey.

In Fig. 14 we contrast the greatest depth of mixing in the winter, in March 2012 (right) with the distribution one year earlier (left). Every winter there is a region of very deep mixing that extends from the westernmost regions of the Gulf of Alaska to the dateline, but usually it does not penetrate far into the central Gulf of Alaska. This past winter has been significantly different with the deepest mixing in the Gulf of Alaska that we have seen at least in the last decade and probably much longer. At Ocean Station Papa the surface mixed layer at the end of March 2012 was 130 metres deep, compared with 100 metres a year ago. This should lead to an abundant supply of nutrients and micro-nutrients for the start of spring in the Gulf of Alaska.

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2.1.3 Qualitative analysis of data sources/processes for use in the derivation of thermal ocean properties

Lt(N) Dan Roy, Formation Oceanographer, Maritime Pacific Headquarters.

MetOc is a section of the Maritime Pacific Headquarters of the Department of National Defence dealing with Meteorology and Oceanography issues. They are part of a larger program to assist in building the overall maritime picture. The primary goal is assessment of the ocean environment in order to primarily conduct operational oceanography. They produce 20 different products including SST, temperature at depth, chlorophyll products. MetOc employs 4 different and unique systems that use in-situ data such as bathythermographs, satellite data and ocean modelling. These 4 systems include: Spaceborne Ocean Intelligence Network (SOIN) (Fig. 1), Ocean Workstation System (OWS) (Fig. 2), Environmental Sensing (Polar Epsilon) (Fig. 3), Radarsat-2 imagery analysis (Figs. 4 and 5). MetOc aims to provide support to research institutions and looking forward to working with other government and non-government departments.

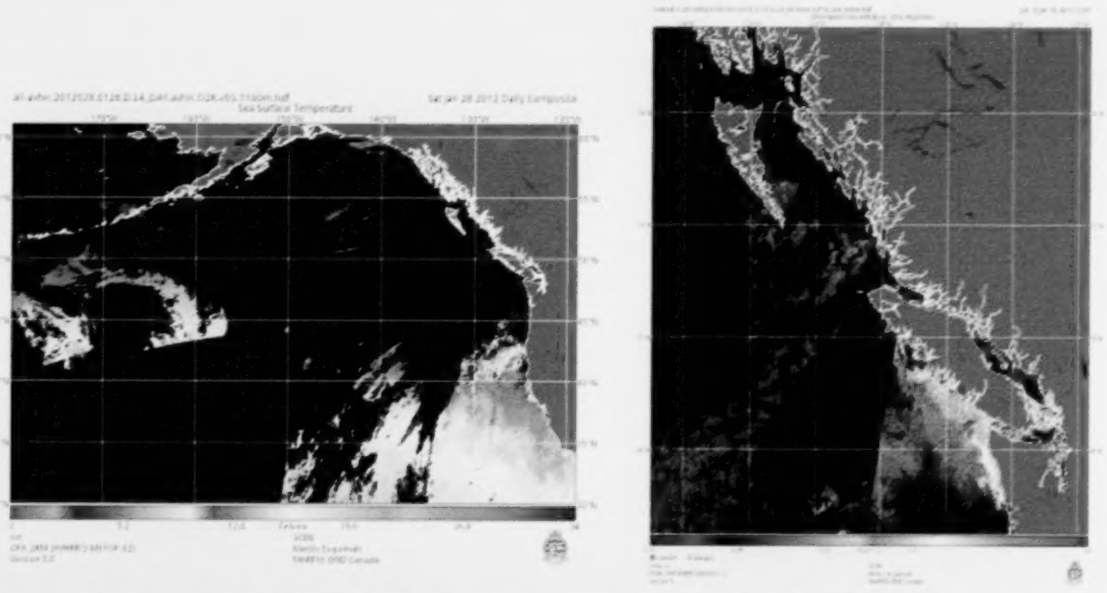


Figure 1. Composite of all AVHRR images of SST for 28 Jan 2012 produced by SOIN (left) and Chlorophyll image produced by SOIN (right).

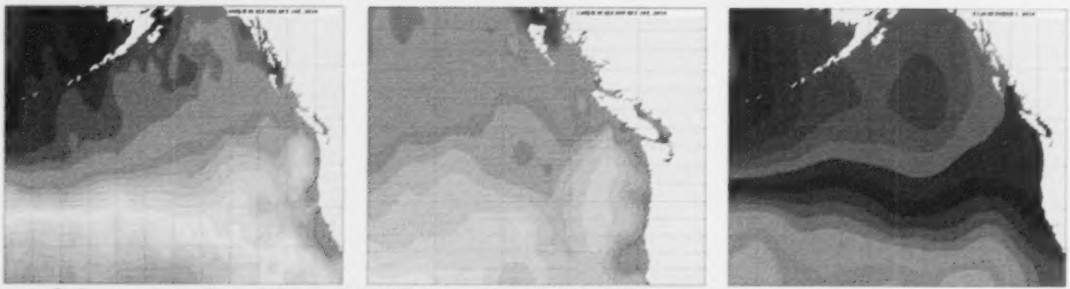


Figure 2. Images produced through OWS from NOAA AVHRR images to produce SST at 400 km basin scale (left) and mesoscale (middle) and temperature at 150m depth 400 km scale (right).

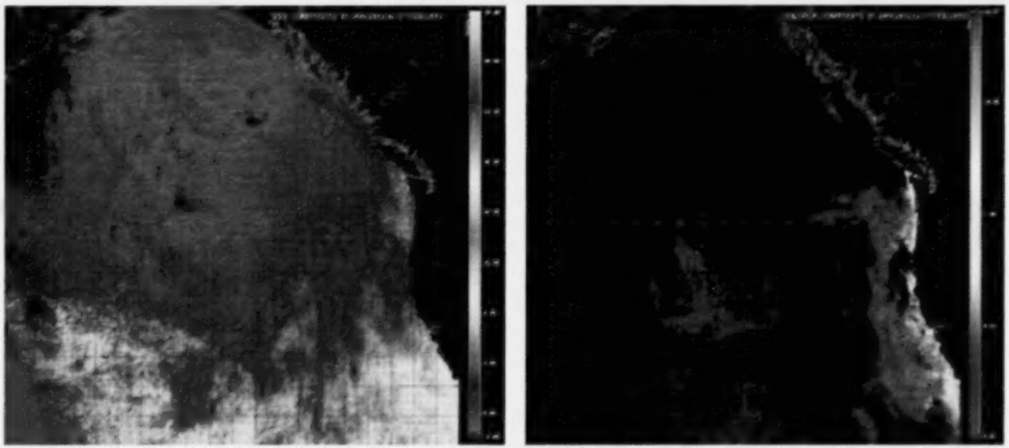


Figure 3. SST (right) and Chlorophyll (left) composites for 31 Jan – 7 Feb 2012 from the environmental sensing system using the MODIS Aqua and Terra Satellites.

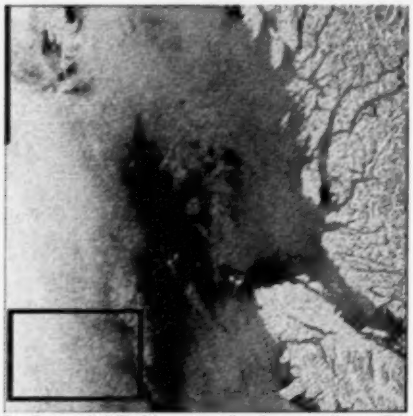


Figure 4. 19 Aug 2011, Radarsat-2, ScanSAR Narrow A, Ascending, Right Looking, VV-VH polarization.

2.1.4 Wind-Driven upwelling/downwelling along the west coast of North America (1950-2011) and Shelf/Shelf-Break Conditions off Vancouver Island in 2011

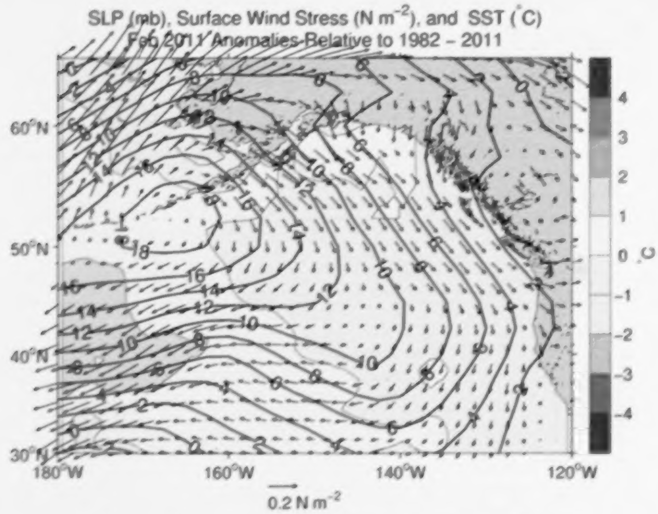
Roy Hourston and Richard Thomson, Fisheries & Oceans Canada

Highlights:

- In 2011 there continued to be stronger-than-average upwelling-favourable (north-westerly) winds along the coast of British Columbia that have persisted since the late 1990s. This was generally due to a weaker-than-average Aleutian Low and stronger-than-average North Pacific High, which were also associated with stronger-than-average downward (convergent) Ekman pumping in the Gulf of Alaska in 2011(Figs. 1-3).
- Between March and April, 2011, there was a dramatic transition from an intense to weak Aleutian Low and strengthened North Pacific High that triggered a spectacular reversal of near-surface wind-driven shelf-break currents from poleward to equatorward. These events were linked through the reversal of along-shore surface winds, and the current reversal also drove associated changes in water level, temperature, and salinity. Although 2011 summer and fall current velocity data are not yet available, this strong reversal suggests that the timing of the spring transition to upwelling conditions was near average in 2011.

Due to their link to offshore surface Ekman transport and compensating onshore transport at depth, the duration and intensity of upwelling-favourable (north-westerly) winds are good indicators of coastal productivity. To gauge low-frequency variability in coastal productivity, we have summed upwelling-favourable-only wind stresses by month along the west coast of North America from 45°-60°N latitude (Fig. 4). Fig. 5 shows the monthly mean integrated upwelling anomalies smoothed using a five-year running mean for the period 1948-2011. The regime shift in the late 1970s appears as a sharp transition from stronger to weaker upwelling-favourable winds. Upwelling-favourable winds have been stronger than average throughout the 2000s. In previous State of the Ocean Reports, we speculated that a repeat of the mid 1970s regime shift to weaker-than-average upwelling appeared imminent. However, stronger-than-average upwelling-favourable winds generally continued through 2011 as far north as 59°N (Fig. 6). February and December, 2011, were characterized by strong, positive, upwelling-favourable wind stress anomalies on par with those in 2006.

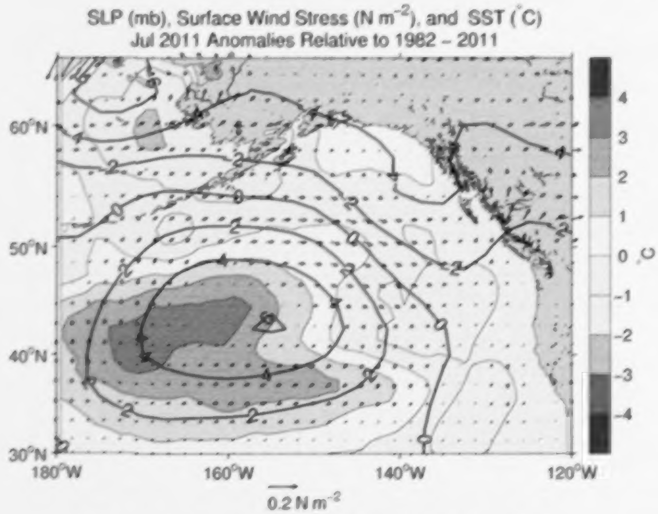
We have also examined the downwelling-favourable winds by considering only the poleward component of the alongshore wind stress; anomalies of the monthly poleward sums are shown in Fig. 7. Here, the regime shift in the late 1970s is characterized by a latitude-dependent transition. Southward of 48ºN, the transition is to weaker downwelling (shifting from average to below-average), whereas northward of this latitude the transition is to stronger downwelling (changing from below average to stronger than average). The major El Niños of 1982-83 and 1997-98 are characterized by stronger-than-average downwelling. The largest anomalies and greatest spatial extent are positive, beginning in 1998 and extending over the range of latitude from 45-60ºN through to the present. A more detailed (non-filtered) examination of the last six years shows mostly positive downwelling anomalies over this period, with strong (downwelling-favourable) poleward winds in the winter of 2006-2007 and stronger-than-average downwelling favourable poleward winds beginning mid-year in 2009 that continued to the end of 2011, except for February and December, 2011 (Fig. 8).



SLP (mb), Surface Wind Stress (N m^{-2}), and SST (°C)
Feb 2011 Anomalies Relative to 1982 – 2011

60°N
50°N
40°N
30°N
180°W
160°W
140°W
120°W
0.2 N m^{-2}
4
3
2
1
0
-1
-2
-3
-4
°C

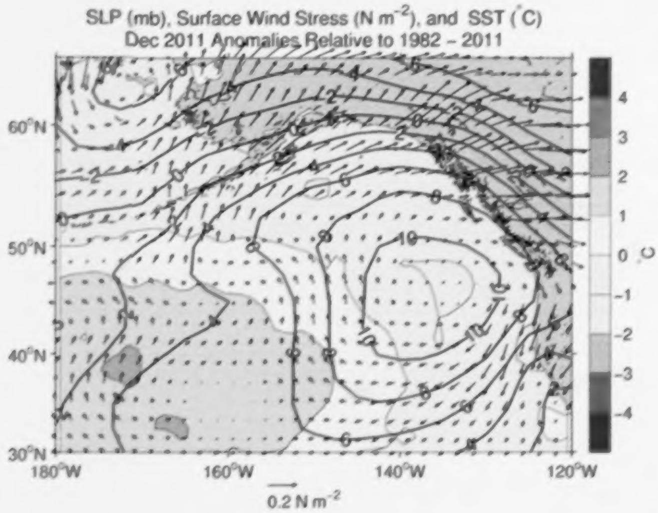
Figure 1. Anomalies (relative to 1982-2011) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of February 2011.



SLP (mb), Surface Wind Stress (N m^{-2}), and SST (°C)
Jul 2011 Anomalies Relative to 1982 – 2011

60°N
50°N
40°N
30°N
180°W
160°W
140°W
120°W
0.2 N m^{-2}
4
3
2
1
0
-1
-2
-3
-4
°C

Figure 2. Anomalies (relative to 1982-2011) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of July 2011.



SLP (mb), Surface Wind Stress (N m^{-2}), and SST (°C)
Dec 2011 Anomalies Relative to 1982 – 2011

60°N
50°N
40°N
30°N
180°W
160°W
140°W
120°W
0.2 N m^{-2}
4
3
2
1
0
-1
-2
-3
-4
°C

Figure 3. Anomalies (relative to 1982-2011) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of December 2011.

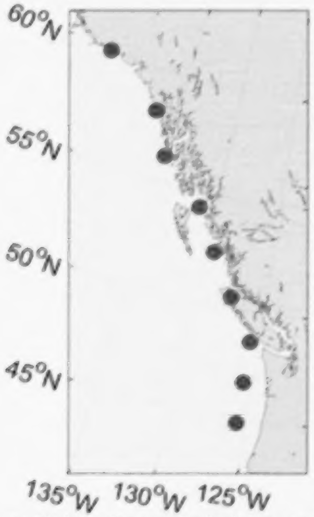


Figure 4. NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations.

As indicated by Fig. 8, the downwelling index reaches its highest magnitude during winter and fall. High winter values in March and September 2011 were due to intensification and/or an eastward shift of the Aleutian Low. Similarly the shift from negative to positive downwelling index values in the winter of 2006-07 represented an eastward shift plus intensification of the Aleutian Low. Thus variations in the downwelling index are due to variability in the Aleutian Low, and consist of a combination of east-west shifts in the centre of the Low and variations in its strength.

Both upwelling and downwelling indices are positive through much of the 2000s (Figs. 5 and 7), suggesting an overall increase in wind speed and wind stress, regardless of wind direction. While the effects on upwelling and alongshore advection are dependent on the wind direction, the effects on mixed-layer depth and Ekman pumping by the generally positive windstress curl in the Gulf of Alaska in winter should be mainly related to wind strength. The long-term effects in the northeast Pacific of changes in scalar wind properties is unclear, but could impact overall productivity.

More detailed observations along the west coast of Vancouver Island in 2011 are shown in Fig. 10. It shows the effects of the transition from an intense Aleutian Low in March to a weak Aleutian Low and strong North Pacific High in April (Fig. 11). Over this transition, along-shore winds and currents shifted from poleward to strongly equatorward, temperatures cooled with respect to climatology while salinities increased reflecting increased upwelling, and water levels dropped dramatically due to offshore transport. Although 2011 summer and fall current velocity data are not yet available, if this strong current reversal represents the spring transition its timing was near normal in 2011.

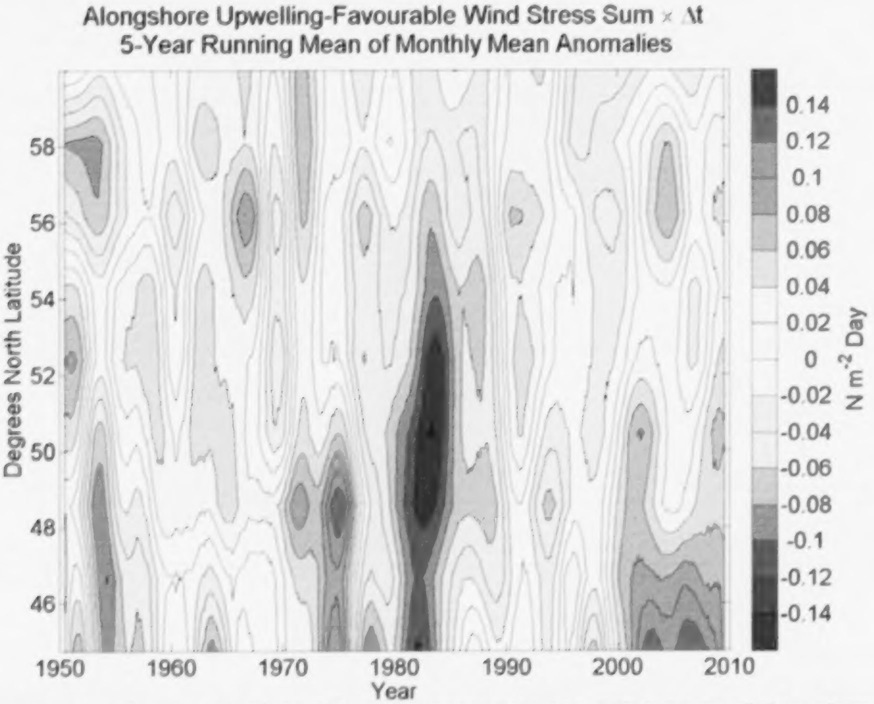


Figure 5. Five-year running means of monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°-60° N.

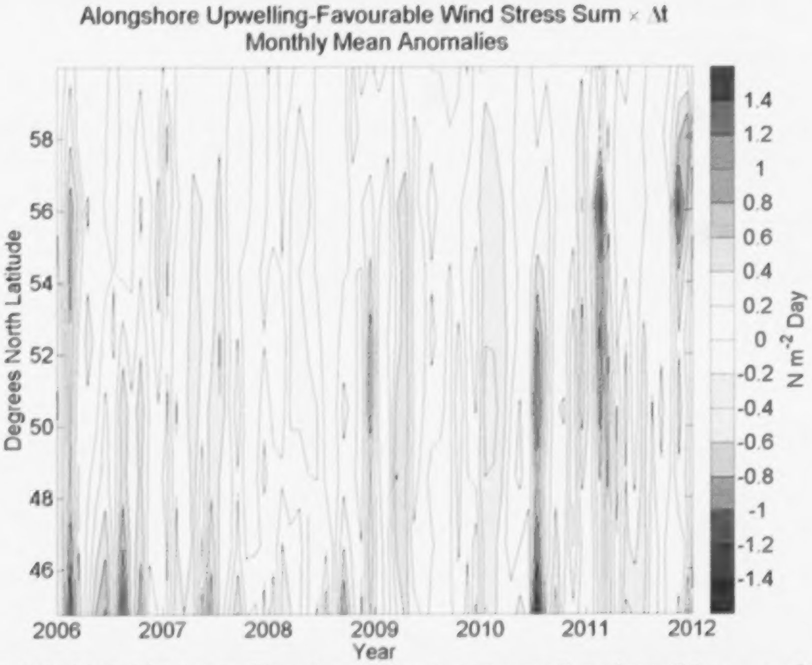


Figure 6. Recent (2006 to 2011) non-filtered monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°-60° N.

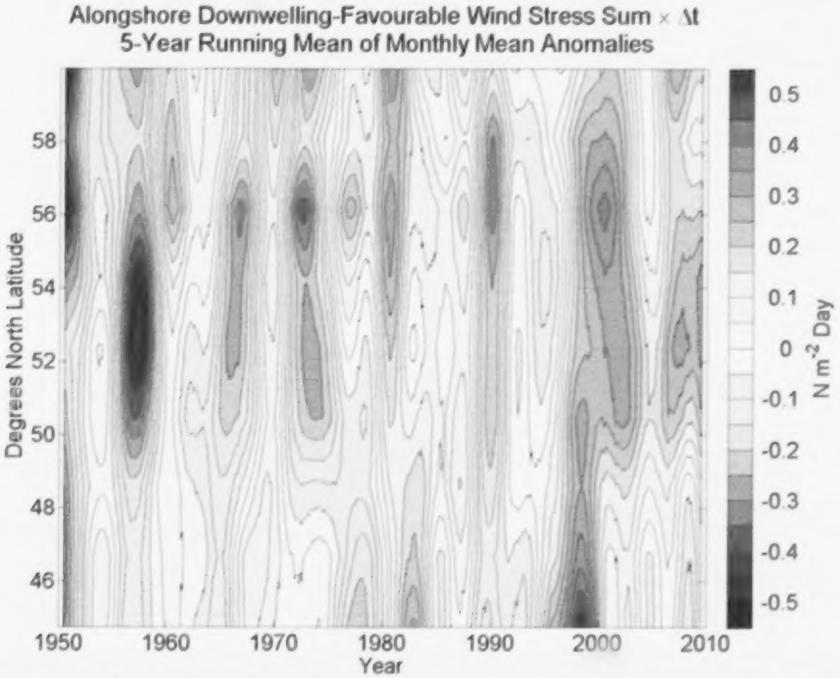


Figure 7. Five-year running means of monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45°-60° N.

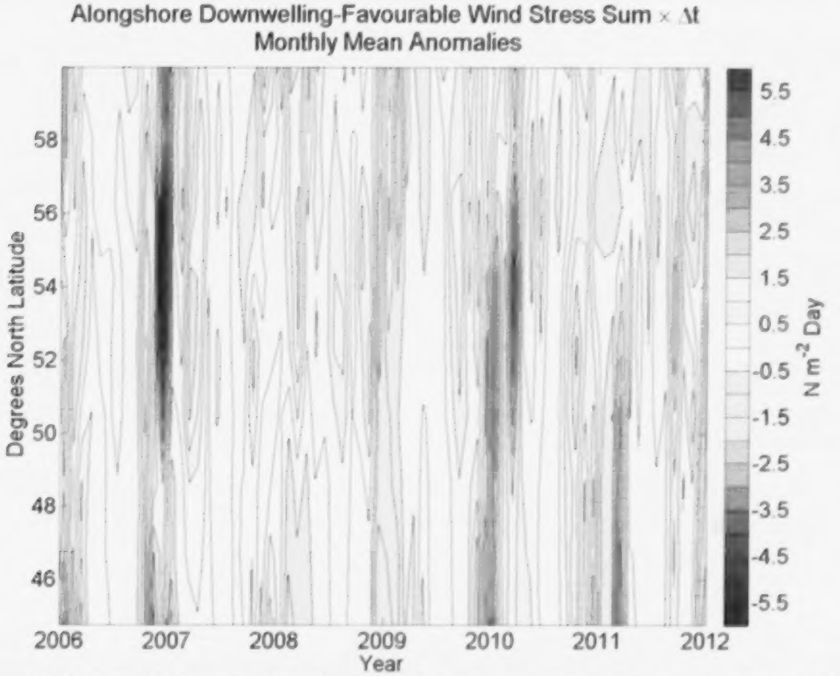


Figure 8. Recent (2006 to 2011) non-filtered monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45°-60° N.

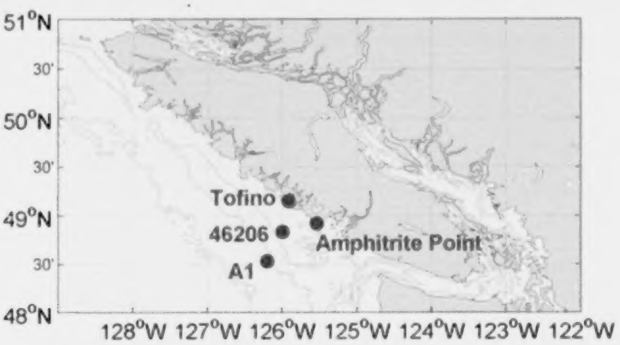

51°N
30'
50°N
30'
49°N
30'
48°N
Tofino
46206
Amphitrite Point
A1
128°W 127°W 126°W 125°W 124°W 123°W 122°W

Figure 9. West coast station locations for shelf break currents (A1), sea-surface temperature and wind stress (meteorological buoy 46206), salinity (Amphitrite Point lighthouse), and water level (Tofino).

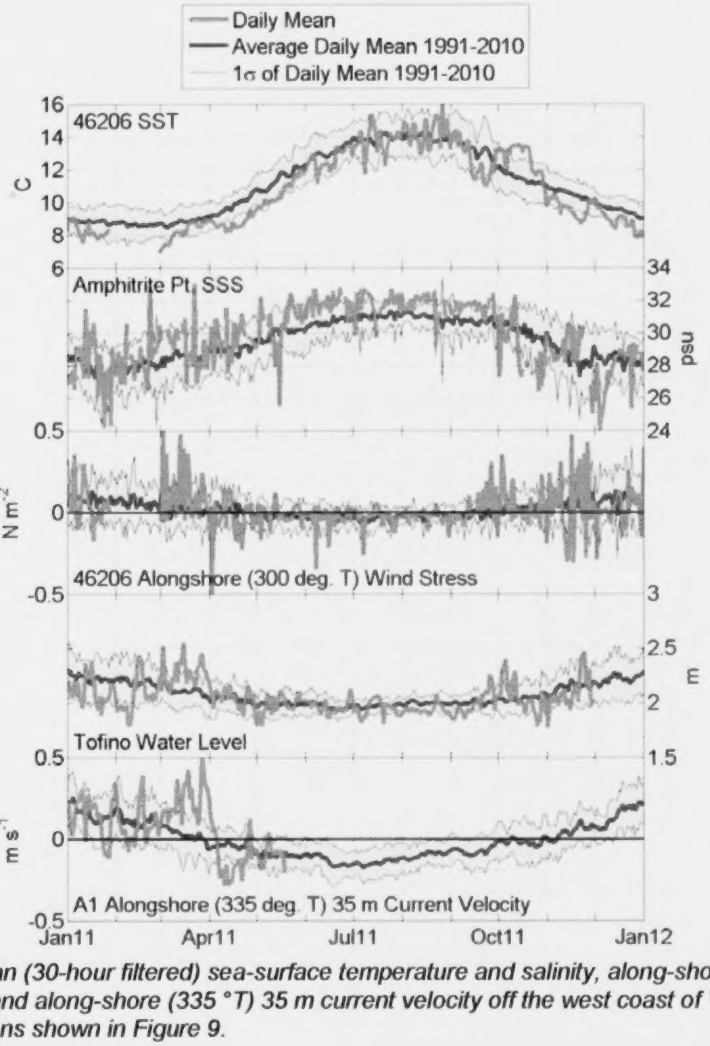
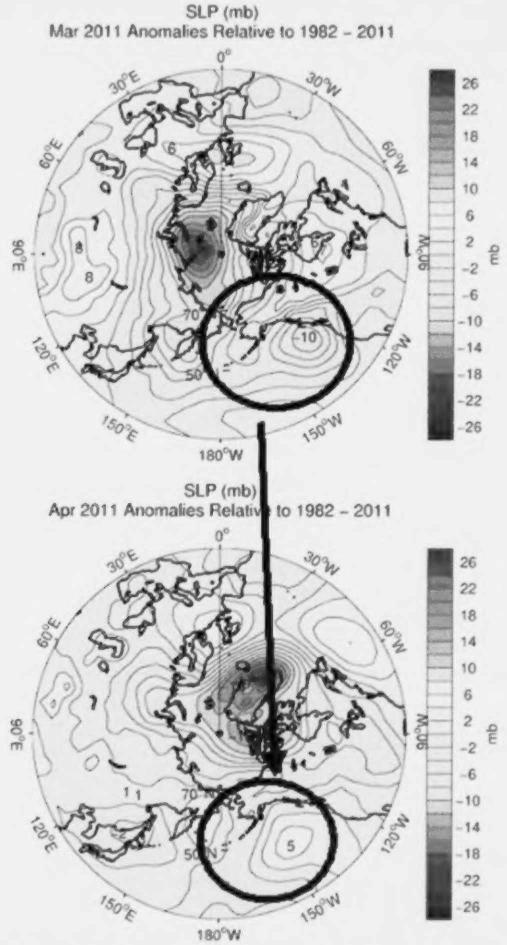


Figure 10. Daily mean (30-hour filtered) sea-surface temperature and salinity, along-shore (300 °T) wind stress, water level, and along-shore (335 °T) 35 m current velocity off the west coast of Vancouver Island in 2011 for the stations shown in Figure 9.



SLP (mb)
Mar 2011 Anomalies Relative to 1982 - 2011

SLP (mb)
Apr 2011 Anomalies Relative to 1982 - 2011

Figure 11. Anomalies (relative to 1982-2011) of sea-level pressure for the months of March (top) and April (bottom) in 2011. Black circle shows the effects of a transition between a stronger-than-average Aleutian Low in March to a weaker-than-average Aleutian Low and stronger-than-average North Pacific High in April.

Acknowledgements

NCEP/NCAR Reanalysis-1 sea-level pressure and wind stress and Reynolds Optimum Interpolation (OI) V2 SST data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/. Literature references for these data are given below.

References

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woolen, J., Chelliah. M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., van del Dool, H., Jenne, R., Fiorino, M. 2001. The NCEP–NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bulletin of the American Meteorological Society* 82: 247–267.

2.1.5 Sea level in British Columbia, 1910 to 2011

Bill Crawford, Fisheries and Oceans Canada

The Canadian Hydrographic Service monitors levels along the BC coast. The records below show annual deviations from a long-term average at three ports. Both Tofino and Victoria have records than began in 1910, while the record at Prince Rupert began in 1912.

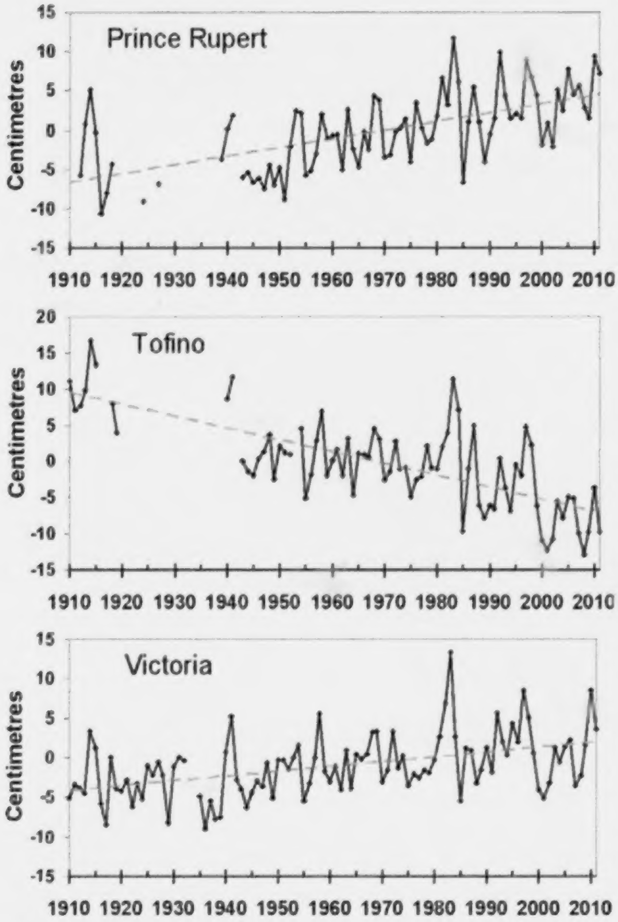


Figure 1. Graphs of annual-average sea levels at three British Columbia ports. Long-term average linear trends are plotted as dashed red lines.

Average sea levels in 2011 were lower at all three ports than in 2010, and within a few centimetres of the long term trends, shown by red dashed lines in Fig. 1. The years of highest sea levels at Tofino and Victoria generally coincide with El Niño events (2010, 1997, 1983) when winter winds typically blow more from the south.

The linear trend at each port is listed below (in cm/century):

Prince Rupert	+11
Victoria	+6
Tofino	-16

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so that local sea level is dropping at an average rate of 16 cm per 100 years.

The next Cascadia Subduction Zone earthquake could drop the land at Tofino and along the west side of Vancouver Island by as much as a metre, and also send a major tsunami toward the BC coast.

Global sea levels rose by 17± 5 cm in the 20th century. Satellite observations from 1993 to 2010 indicate global sea levels rose at a rate of about 30 cm per century. Lower rates at Victoria and Prince Rupert may be due to vertical tectonic motion, combined with decadal variability in winds over the northeast Pacific Ocean.

The Intergovernmental Panel on Climate Change (IPCC 2007) predicts sea level to rise by 20 to 60 cm over the 21st century, but recent observations of ice melt in Greenland and Antarctica suggest these projections might be too low. Therefore, we can expect to observe greater rates of sea level rise in British Columbia in the future than we saw in the 20th century.

2.1.6 Sea surface temperature and salinity trends observed at lighthouses

Peter Chandler, Fisheries & Oceans Canada

Temperature and salinity are measured daily at the first daylight high tide at 13 shore stations as part of the DFO Shore Station Oceanographic Program. The first measurements began in 1914 and 13 stations continue to operate today, providing a database suitable to examine the long-term trends of conditions in coastal waters.

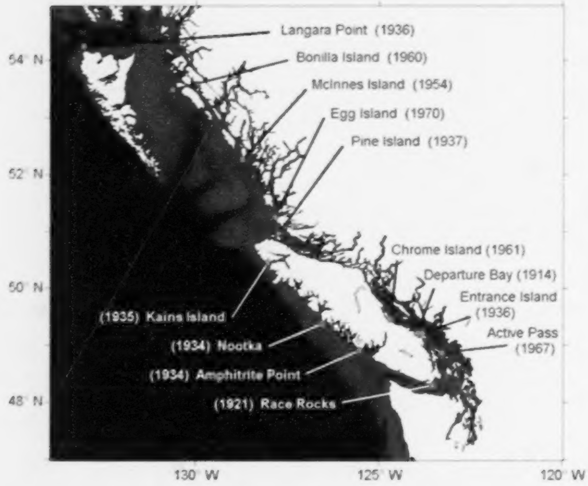

Langara Point (1936)
Bonilla Island (1960)
McInnes Island (1954)
Egg Island (1970)
Pine Island (1937)
Chrome Island (1961)
Departure Bay (1914)
Entrance Island (1936)
Active Pass (1967)
(1935) Kains Island
(1934) Nootka
(1934) Amphitrite Point
(1921) Race Rocks
54° N
52° N
50° N
48° N
130° W
125° W
120° W

Figure 1. The 13 stations in the network and the first year of the data record.

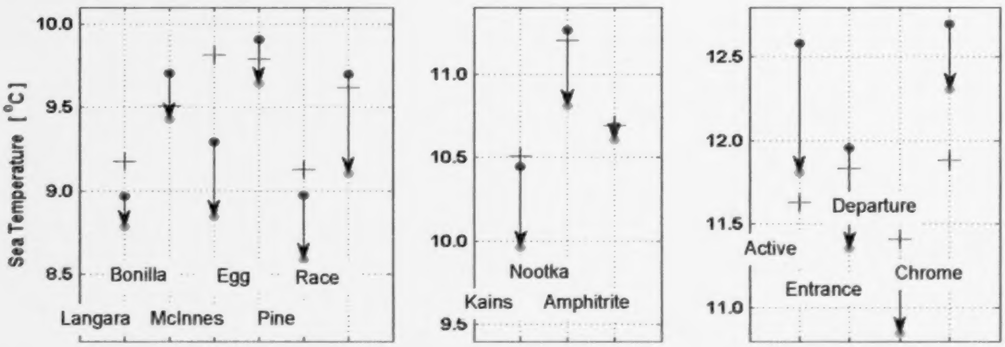


Figure 2. The average daily sea surface temperature in 2010 (blue dots) and 2011 (red dots). The crosses represent the mean annual temperature based on 30 years of data (1981-2010).

The observations at all stations show the average daily sea surface temperature (Fig. 2) was cooler in 2011 than in 2010. On average the northern stations were 0.28 °C cooler; the west coast stations 0.40 °C cooler; and the Strait of Georgia stations 0.55 °C cooler than in the previous year. All stations, with the exception of Active Pass and Chrome Island, experienced temperatures in 2011 that were below the thirty-year average (1981 – 2010).

The annual temperature signal (Fig. 3) in the Strait of Georgia shows a greater range, and typically a peak about 10 days before stations on the west and north coasts. In 2011, generally below-normal temperatures were observed through the year at all stations, although there were some periods in summer that were warmer than the 30-year normal.

The annual salinity signal (Fig. 4) in the three regions of the BC coast show differences due to the fresh water influences: the Fraser River freshet in the Strait of Georgia, the winter rains along the west coast, and the relative stability along the north coast. Conditions in 2011 were fresher than normal at most stations, with the large and late snowmelt causing significant lower-than-normal salinity at Departure Bay.

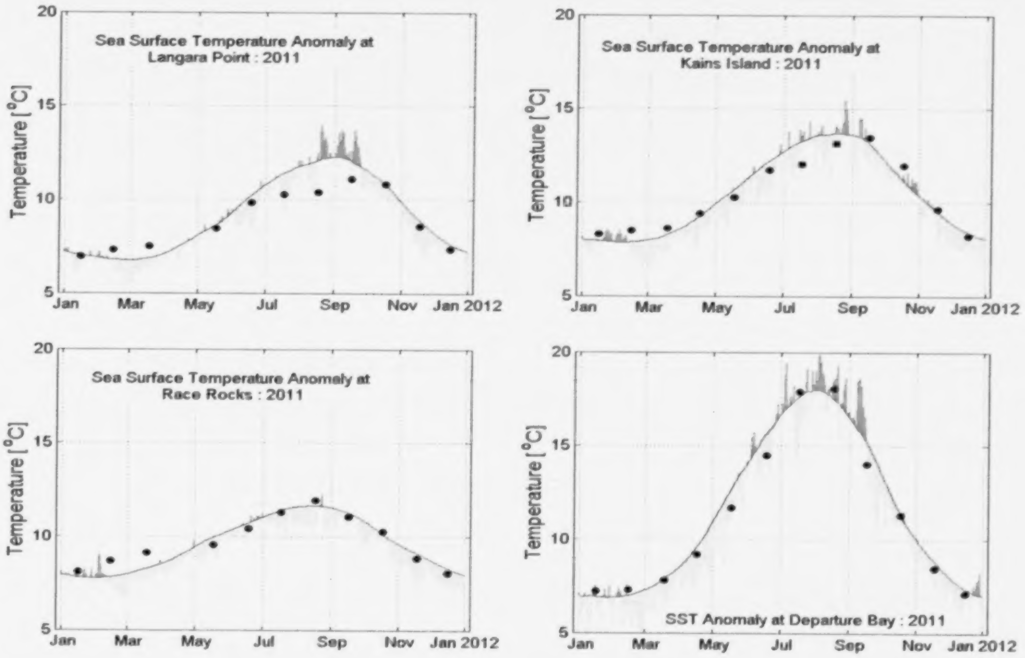


Figure 3. Daily temperatures observed in 2011, and the annual cycle (calculated from 1981-2010 data), at stations representing the north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average 30 year temperature for each day are shown in red (blue). The black dots represent the monthly temperature anomalies observed in 2010.

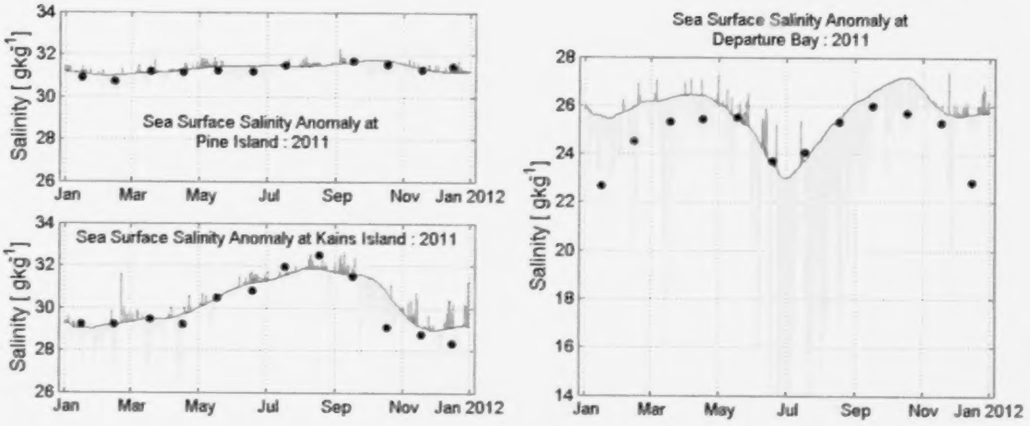


Figure 4. Daily salinity observed in 2011, and the annual cycle (calculated from 1981-2010 data), at stations representing the North Coast, West Coast and Strait of Georgia. Positive-saltier (negative-fresher) anomalies from the average 30 year salinity for each day are shown in red (blue).

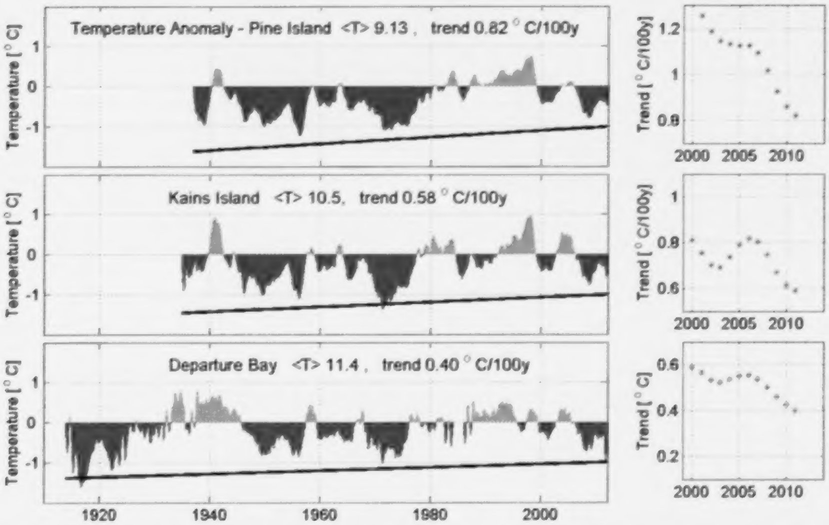


Figure 5. Long-term time series of daily temperature anomalies, averaged over 12 months, at stations representing the north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average temperature <T> are shown in red (blue). Black lines are the trends. The panel to the right shows the slope of the trend lines calculated using only data up to the year shown on the x axis.

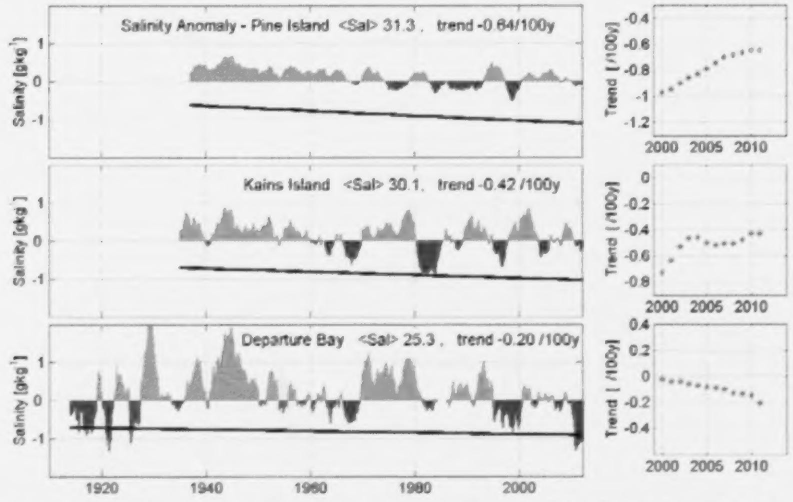


Figure 6. Long-term time series of daily salinity anomalies, averaged over 12 months, for north coast, west coast and Strait of Georgia stations. Positive-saltier (negative-fresher) anomalies from the average salinity <Sal> are shown in red (blue). Black lines are the trends. The panel to the right shows the slope of the trend lines calculated using only data up to the year shown on the x axis.

Fig. 5 shows a consistent warming trend at all of the BC shore stations determined from the slope of the temperature data assuming a linear change over the entire time series. The Strait of Georgia waters continue to warm at a faster rate than those on the west coast, which are warming faster than those of the north coast. The right panel shows that the slope of the trend varies with time, suggesting either a cyclic (PDO) or regime shift influence on the sea surface temperatures. A similar trend analysis applied to the salinity data (Fig. 6) shows a trend toward fresher water along the BC Coast. The salinity signal is influenced by local conditions and while evident, the trends are not statistically significant at the 95% confidence level.

2.1.7 Mesozooplankton in the Northeast Pacific in 2011

Sonia Batten, Sir Alister Hardy Foundation for Ocean Science, UK

Summary: Indices of zooplankton biomass and spring timing were within the range seen before, and were consistent with cool conditions.

Spring 2011 data from Continuous Plankton Recorder surveys have been finalised at the time of writing, while data for July to Sept are only partially complete. Sampling occurs approximately monthly 6-9 times per year between March and October in the off-shore NE Pacific. The spring mesozooplankton biomass peak in 2011 was flat and relatively sustained, as has been seen in previous cool years, and biomass for the year is likely to show a small positive anomaly when all data are complete, (Fig. 1) quite in contrast to 2010.

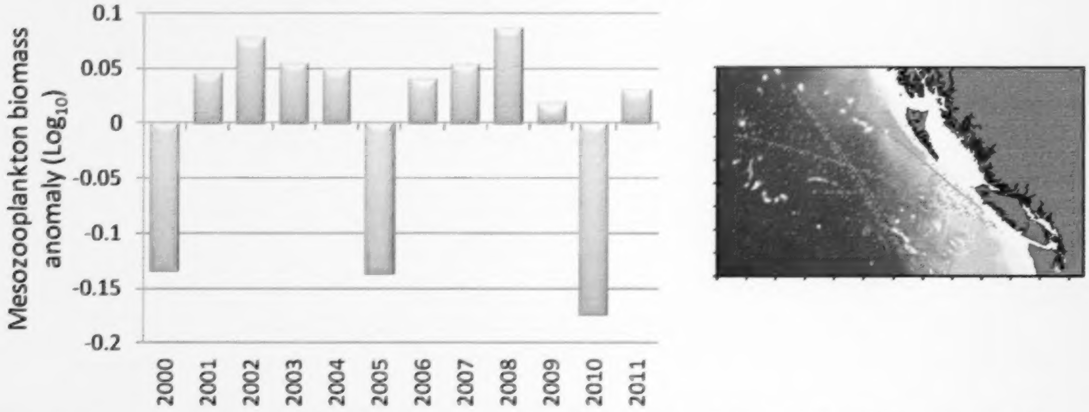


Figure 1. Annual mesozooplankton biomass anomaly(left) based on data from the CPR survey for the samples shown in the region above(right).

Seasonal timing indices for the abundant large copepod *Neocalanus plumchrus/flemingeri* are shown in Fig. 2.

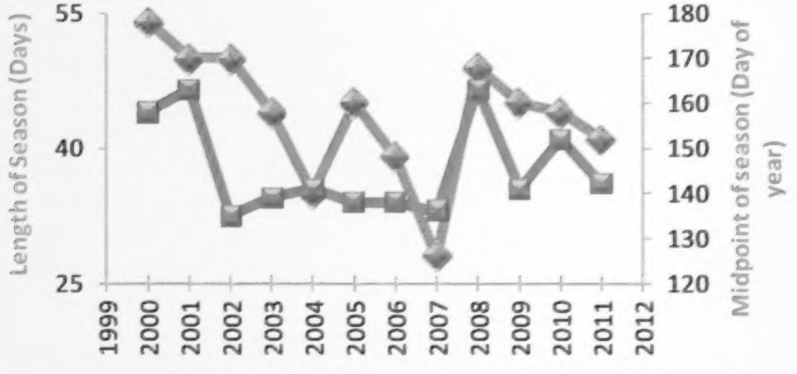


Figure 2. Day of year at which 50th percentile of the cumulative biomass of N. plumchrus/flemingeri *was reached (red line) and length of season (blue line) as the number of days between the 25th and 75th percentile, for the offshore region above.*

These copepods live at the ocean surface for only a month or two, near the time of maximum size and abundance. Changes in timing of their growth will determine when they are available as food for predators that take advantage of this organism's peak abundance. The timing of the mid-point of the season and its duration in 2011 were in the range seen before, and in-line with the cool La Niña conditions. The season mid-point for the time series as a whole correlates with the annual PDO index, ($r^2=0.37$, $p<0.05$) though a slightly later peak in 2011 would have been expected from this relationship.

Spring community composition in 2011 showed an increase in the contribution of large organisms and a reduction compared to 2010 in the proportion of small copepods. The large numbers of the small copepod *Pseudocalanus* seen in 2010 reduced to near average numbers in 2011.

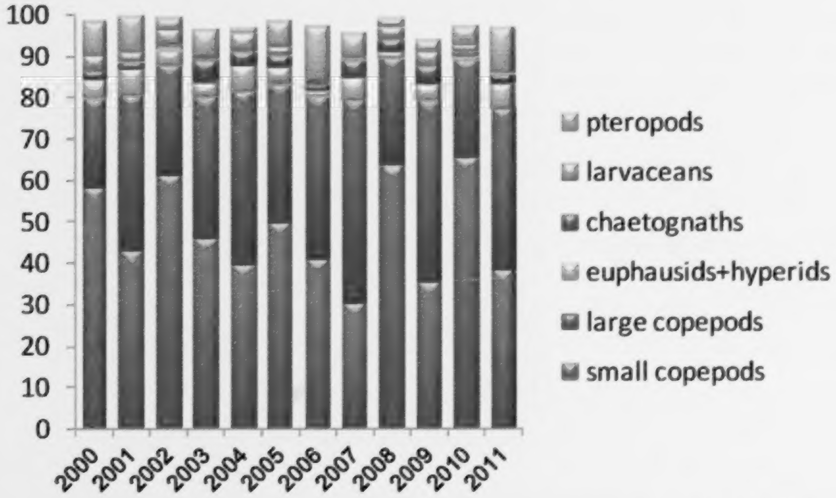


Figure 3. Contribution to the mean spring (April, May and June) zooplankton abundance by each major group as a percentage.

In summary, 2011 showed few surprises and indices of biomass, timing and composition were all within the range seen earlier in the time series.

Reference

http://pices.int/projects/tcprsotnp/default.aspx for data and more information

2.1.8 Ocean Conditions off Newport, Oregon in 2011

Bill Peterson, Northwest Fisheries Science Centre, National Oceanic and Atmospheric Administration, USA

The trend towards cold ocean conditions in the northeast Pacific that started in September 2007 was interrupted by a moderately strong El Niño event from August 2009 to May 2010. However, in June 2010 La Niña conditions were initiated and continued through early 2012. It is noteworthy that the Pacific Decadal Oscillation (PDO) had some very negative values from mid 2011 through November 2011, when one of lowest values on record was seen, -2.33. Subsequently, the PDO began to weaken as did the Oceanic Niño Index (ONI), signalling the end of the strong La Niña. Neutral "Niño" conditions are expected in equatorial waters by April or May 2012. See Crawford 2012 (elsewhere in this research document) for insight into PDO, ONI, and Gulf of Alaska conditions. Despite a strongly negative PDO in 2011, upwelling in 2011 was relatively weak in April and May, strengthened moderately in mid June but then ended in mid September. Cumulative upwelling in 2011 was the 12th lowest value since 1998.

Ocean Conditions

A good indicator of good vs. poor ocean conditions for many marine species is the temperature and salinity (T-S) of bottom waters on the continental shelf off Newport, during the May to September upwelling season. As mentioned above, upwelling was relatively weak during 2011 and this is borne out in the T-S properties of deep shelf waters. As can be seen in Fig. 1, the summer of 2011 was characterized by temperatures and salinities that were near the median for the 15-year time series.

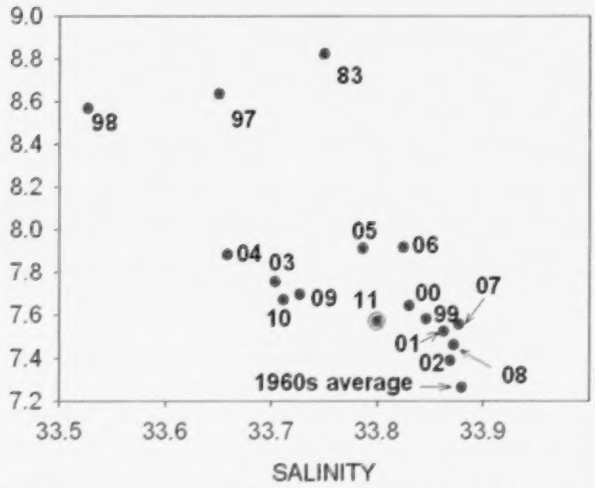


Figure 1. Temperature and salinity measured at a depth of 50 m along the Newport Line at station NH 05 where the water depth is 62 m. Note that the average T-S value in 2011 (red circle) was near the median value for the 15-year time series, as expected during summers of weak-to-moderate upwelling.

Zooplankton: Northern Copepods

Despite relatively weak upwelling during May to September 2011, the "northern copepod" biomass had the highest values of our 16 year time series (Fig. 2). The biomass of these "northern copepods" is a particularly good index of "productive ocean conditions" with respect to Columbia River coho and Chinook salmon and coho salmon from Oregon's coastal streams, because the index is well correlated with their returns as adult salmon (see Peterson et al. 2011). Northern copepod biomass anomalies appear to index the bioenergetic content of the food chain because northern copepods are lipid-rich. This is important because lipids have roughly twice the bioenergetic content of protein or carbohydrates; thus lipid-rich copepods fuel a food chain that contains lipid-rich juvenile salmon prey such as sand lance, anchovies and herring. Two copepods species providing most of the lipids: *Pseudocalanus mimus* and *Calanus marshallae*.

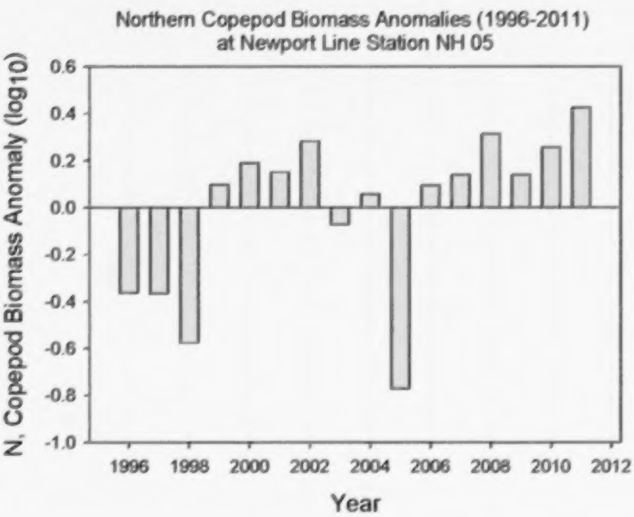


Figure 2. The anomaly of "northern copepod biomass" averaged over May to September, 1996 through 2011. Positive anomalies indicate a high biomass of northern species and indicate good ocean conditions, particularly for salmon. The northern copepods include three species: Pseudocalanus mimus, Calanus marshallae *and* Acartia longiremis.

Zooplankton: Copepod Biodiversity

When the Pacific Decadal Oscillation (PDO), Oceanic Niño Index (ONI), sea surface temperature and copepod biodiversity are compared as a time series, it is seen that these variables are well correlated (Fig. 3). The plots reveal that the anomaly of ocean temperature at NOAA Buoy 46050 tends to track changes in both PDO and ONI. The number of copepod species on the Oregon shelf also tracks these changes and suggests that changes in advection are associated with sign-changes in the PDO and ONI: During negative PDO and ONI, cool waters are transported from the north (along with the cool-water copepod communities contained therein) to the shelf waters of the northern California Current, leading to low species richness. Positive PDO and ONI generally bring more copepod species. This pattern held during 2011: the PDO and ONI were negative, coastal waters were cold, and copepod species richness was quite low. Negative values of each of these three indicators, along with the high biomass of northern copepod species, generally result in good returns of salmon 1.5 to 2 years later.

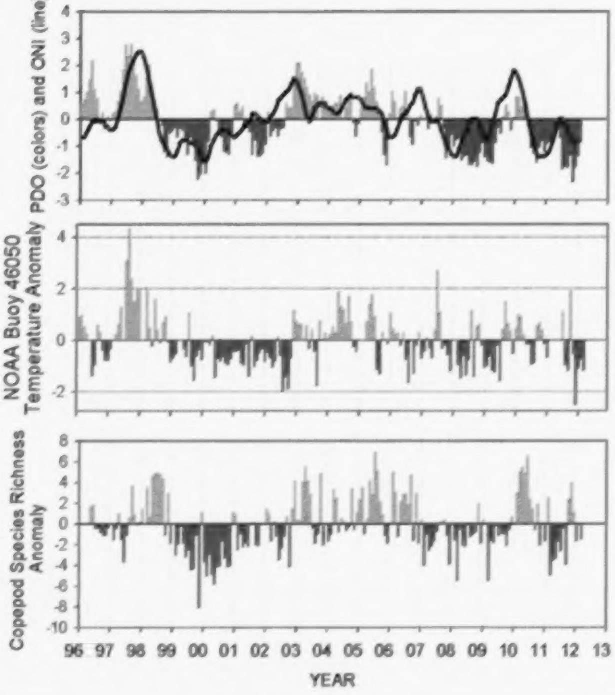


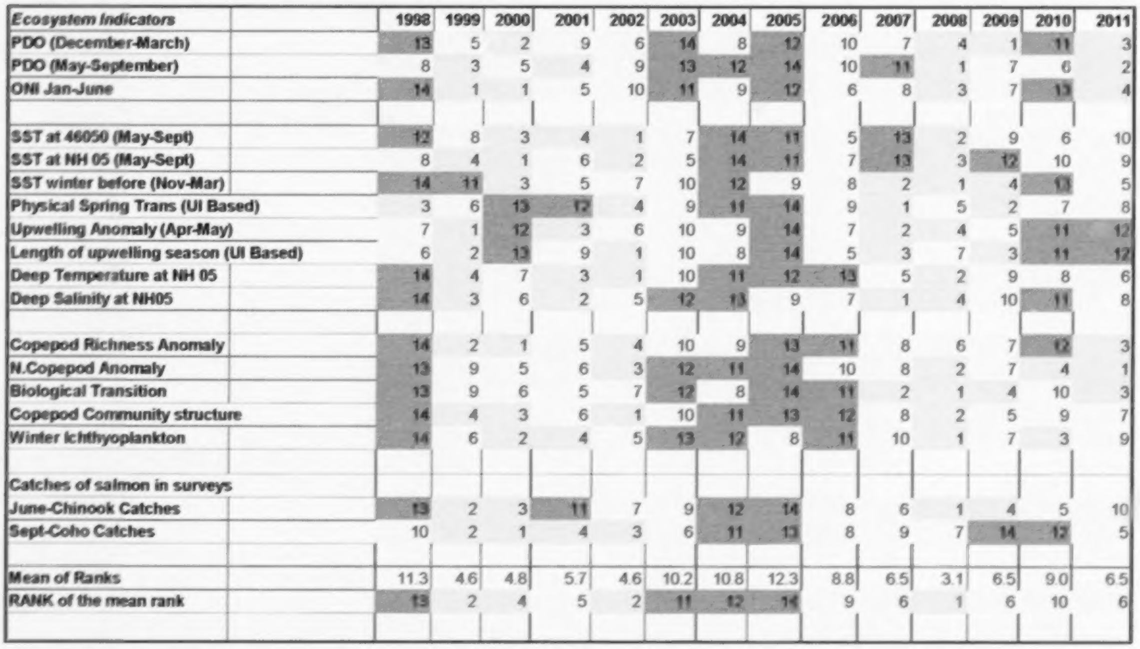
Figure 3. Top: Time series of the PDO and ONI since 1996. Middle panel: SST measured at NOAA Buoy 46050, which is approx. 22 miles due west of Newport Oregon. Bottom: Copepod species richness anomalies from zooplankton samples taken at a station 9 km from shore along the Newport Hydrographic line.

Copepod species richness anomalies are based on the number of copepod species in bimonthly plankton net surveys. The data shown this year are slightly different from past reports because we updated the climatology against which the anomalies are calculated to include all data from 1996 to 2010 (whereas past anomalies were based on the 1996 to 2005 baseline).

Note that both the PDO and ONI have had negative values from mid 2010 (indicating good ocean conditions); SST did not track this closely (but note that the buoy was out-of-service for several months in early 2011. Copepod species richness anomalies were negative in 2011, as expected during periods of negative PDO.

Integrated Assessment

Our complete set of ecosystem indicators that are used to provide outlooks for salmon returns in the next two years suggest that the 2011 was a confusing year. As discussed above, even though the PDO and ONI were strongly negative (indicators of good ocean conditions for coho and Chinook salmon), other indicators suggested moderate conditions (e.g. SST was moderately high). The spring transition was late (rank 8 of 14; lower ranks would signal "good" ocean conditions). The upwelling was weak in spring and the spring-to-autumn upwelling period was among the shorter seasons (rank 12 of 14). Deep temperature and salinity were near the median, yet the copepod indicators were among the BEST observed in recent times. Overall, 2011 ranked 6th of 14 years or slightly above average (Fig. 4). Time will tell if salmon returns were slightly above average in 2012 (coho) and 2013 (fall and spring Chinook runs). Ranks of all indices are shown in the table below.



Ecosystem Indicators		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PDO (December-March)		13	5	2	9	6	14	8	12	10	7	4	1	11	3
PDO (May-September)		8	3	5	4	9	13	12	14	10	11	1	7	6	2
ONI Jan-June		14	1	1	5	10	11	9	12	6	8	3	7	13	4
SST at 46050 (May-Sept)		12	8	3	4	1	7	14	11	5	13	2	9	6	10
SST at NH 05 (May-Sept)		8	4	1	6	2	5	14	11	7	13	3	12	10	9
SST winter before (Nov-Mar)		14	11	3	5	7	10	12	9	8	2	1	4	13	5
Physical Spring Trans (UI Based)		3	6	13	12	4	9	11	14	9	1	5	2	7	8
Upwelling Anomaly (Apr-May)		7	1	12	3	6	10	9	14	7	2	4	5	11	12
Length of upwelling season (UI Based)		6	2	13	9	1	10	8	14	5	3	7	3	11	12
Deep Temperature at NH 05		14	4	7	3	1	10	11	12	13	5	2	9	8	6
Deep Salinity at NH05		14	3	6	2	5	12	13	9	7	1	4	10	11	8
Copepod Richness Anomaly		14	2	1	5	4	10	9	13	11	8	6	7	12	3
N.Copepod Anomaly		13	9	5	6	3	12	11	14	10	8	2	7	4	1
Biological Transition		13	9	6	5	7	12	8	14	11	2	1	4	10	3
Copepod Community structure		14	4	3	6	1	10	11	13	12	8	2	5	9	7
Winter Ichthyoplankton		14	6	2	4	5	13	12	8	11	10	1	7	3	9
Catches of salmon in surveys															
June-Chinook Catches		13	2	3	11	7	9	12	14	8	6	1	4	5	10
Sept-Coho Catches		10	2	1	4	3	6	11	13	8	9	7	14	12	5
Mean of Ranks		11.3	4.6	4.8	5.7	4.6	10.2	10.8	12.3	8.8	6.5	3.1	6.5	9.0	6.5
RANK of the mean rank		13	2	4	5	2	11	12	14	9	6	1	6	10	6

Figure 4. Stoplight chart showing the ranks of the indicators used to provide outlooks of returns of coho and Chinook salmon to the Columbia River. Green-coloured boxes and low ranks indicate "good ocean conditions" from the viewpoint of a salmon. The overall "integrated" indicator is the "RANK of the mean rank on the bottom line of the table, and for 2011, suggests that this was an "average" year. The values behind the ranks can be seen on the "Ocean Conditions" website:http://www.nwfsc.noaa.gov and click on "Ocean Conditions and Salmon Forecasts" in the box on the right-hand side of the webpage.

Reference

Peterson, William T, Cheryl A. Morgan, Jay O. Peterson, Jennifer L. Fisher, Brian J. Burke and Kurt Fresh. 2011. Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. 79 pp. pdf document available at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/documents/peterson_etal_2011.pdf

2.2 WEST COAST VANCOUVER ISLAND AND PNCIMA

2.2.1 Zooplankton along the BC continental margin: a near-average year

Dave Mackas, Moira Galbraith, and Kelly Young, Fisheries & Oceans Canada

Zooplankton time-series coverage of the British Columbia continental margin extends from 1979 to present for southern Vancouver Island [SVI], from 1990 to present for northern Vancouver Island [NVI] (although with much lower sampling density and taxonomic resolution in 1991 to 1995), and from 1998 to present for southern Hecate Strait (with some scattered earlier sampling between 1983 and 1997). The 'standard' sampling locations in SVI, NVI and Hecate regions are shown in Fig. 1. Additional locations are included in averages when they are available. Samples are collected during DFO research surveys using vertical net hauls with black bongo nets (0.25 m^2 mouth area, 0.23 mm mesh aperture), from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. We have also recently compiled historic data from various shorter term sampling programs in the Strait of Georgia (SoG). Most of the SoG sampling did not follow a standard grid or sampling protocols. Because of time varying taxonomic resolution, the SoG data have been merged into broader categories (size classes within major taxa). Our analyses-to-date of the SoG time series are described else where in this document (see Mackas et al. 2012).

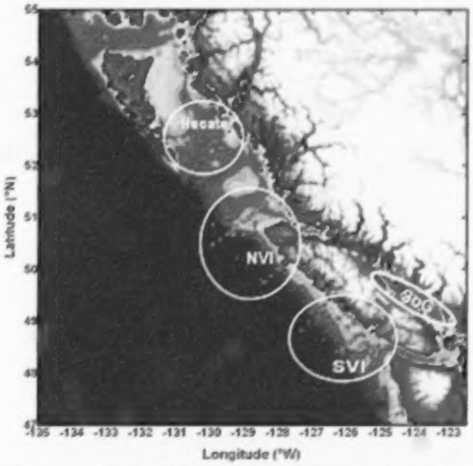


Figure 1. Zooplankton time series sampling locations (red dots) in BC marine waters. Data are averaged within major statistical areas indicated by ovals; the SVI and NVI regions are further classified into shelf and offshore subregions. The PNCIMA (Pacific North Coast Integrated Management Area) includes both NVI and Hecate stat areas. Preliminary results from the SoG time series are described in Mackas et al. 2012 (elsewhere in this research document).

We estimate abundance and biomass for more than 50 zooplankton species in the SVI, NVI and Hecate regions. For all three regions, seasonal variability is intense and somewhat repeatable from year to year. However, because sampling dates vary from year to year, simple annual averages of observations confound seasonal with interannual differences. We deal with this by first estimating a multi-year average seasonal cycle (= "climatology") for each region, using the data from the start of each time series through 2005, and then using these climatologies as baselines against which we can then compare monthly conditions during any single year. To describe interannual variability, our approach has been to calculate within each year a regional, logarithmic (log) scale biomass anomaly for each species and for each month that was sampled. We then average the monthly anomalies in each year to give an annual anomaly (see Mackas 1992 & Mackas et al. 2001 for mathematical details). It is important to note that the anomalies are log scale and therefore multiplicative on linear scale: an anomaly of +1 for a given taxon means that taxon had 10 times higher biomass than in the climatology; an anomaly of -1 means the biomass was 1/10th the climatology.

We have learned from our own and other west coast time series (Mackas et al. 2006) that zooplankton species with similar zoogeographic ranges and ecological niches usually have very similar anomaly time series. We therefore often summarize the interannual variability of multiple species by averaging within species groups. For example, the group 'boreal shelf copepods' is a composite of the copepods *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis*, all of which have distribution ranges that extend from southern Oregon to the Bering Sea. The group 'subarctic oceanic copepods' is a composite of *Neocalanus plumchrus*, *N. cristatus*, and *Eucalanus bungii*; all of which inhabit deeper areas of the subarctic Pacific and Bering Sea from North America to Asia). A third group, 'southern copepods' is a composite of five species with ranges centered about 1000 kilometres south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre).

Fig. 2 shows anomaly time series for these copepod species groups, as well as representative chaetognaths and euphausiids in each of the three BC statistical areas. The range of interannual biomass variability within a species or species group is about one log unit (i.e. factor of 10), and in our regions is about 2-3 times greater than the interannual variability of total biomass. Other features to note are that anomalies often persist for several years and that, in addition to the covariation within species groups mentioned above, there is strong covariation between some species groups. The clearest and most gradually varying signals have been in the three copepod groups and in the chaetognaths. Cool years such as the early 1980s, 1999-2002, and 2007-10 tended to have positive anomalies of boreal shelf and subarctic copepods, and northern chaetognaths. Warm intervals such as 1983, 1993-1998, and 2004-2005 tended to have negative anomalies of these taxa, but positive anomalies of southern copepods and chaetognaths. We now know that positive anomalies of the cool water zooplankton community off Vancouver Island are also associated with good local survival and growth of juvenile salmon, sablefish, and planktivorous seabirds (Mackas et al. 2007; M. Trudel, personal communication).

2011 was a near-average year (anomalies neither strongly positive nor strongly negative) off the west coast. On the SVI continental shelf, and in both shelf and offshore NVI, annual average anomalies of the cool water copepod and chaetognath species groups remained slightly positive in 2011 (usually slightly more positive than in 2010, which was a weak El Niño year and somewhat warmer than 2011), but were well below the strong positive anomalies of the colder years 2007-2009. Conversely, the warm-water southern origin copepods had weak negative anomalies except in the SVI offshore subregion (see below), but were also much less negative than in 2007-2009. Chaetognath and euphausiids anomalies were similar to 2010.

There have been two new signals in the zooplankton time series during the last decade. The first has been increasing incidence of strongly positive annual anomalies of one or more gelatinous zooplankton taxa (Fig. 3). Several high-order zooplankton taxa (with widely differing ecological niches) are classified as "gelatinous zooplankton". However, all have high to very high peak reproductive rates compared to the crustaceans and chaetognaths, and all tend to have "boom and bust" population time series. The most important groups in the SVI, NVI and Hecate regions are:

- Salps and doliolids. These are planktonic tunicates, and are primarily herbivorous (broad spectrum filter feeders)
- Hydromedusae and scyphomedusae ("jellyfish") and ctenophores ("comb jellies"). These are predatory on other zooplankton and sometimes on larval fishes.
- Thecosomatous pteropods. These are planktonic snails. Unlike the previous two groups, their bodies are not gelatinous, but they use a large external gelatinous feeding web to capture their food.
- Doliolids and the pteropod *Clio* were absent or rare in nearly all years before 2002, but since then have been abundant to very abundant in the SVI region in many years (and nearly as abundant in the NVI region).

Years with positive salp anomalies have occurred throughout the time series, but both of the last two years (2009 and 2010) were well above average. A similar pattern is present in the jellyfish time series. As with the long term trend in the copepod species groups, the net effect has been to make the zooplankton community off BC more like the community found in nearshore parts of the California Current System to the south of BC, less like the historical SVI and NVI climatology, and less like the present-day zooplankton community off northern British Columbia and Alaska.

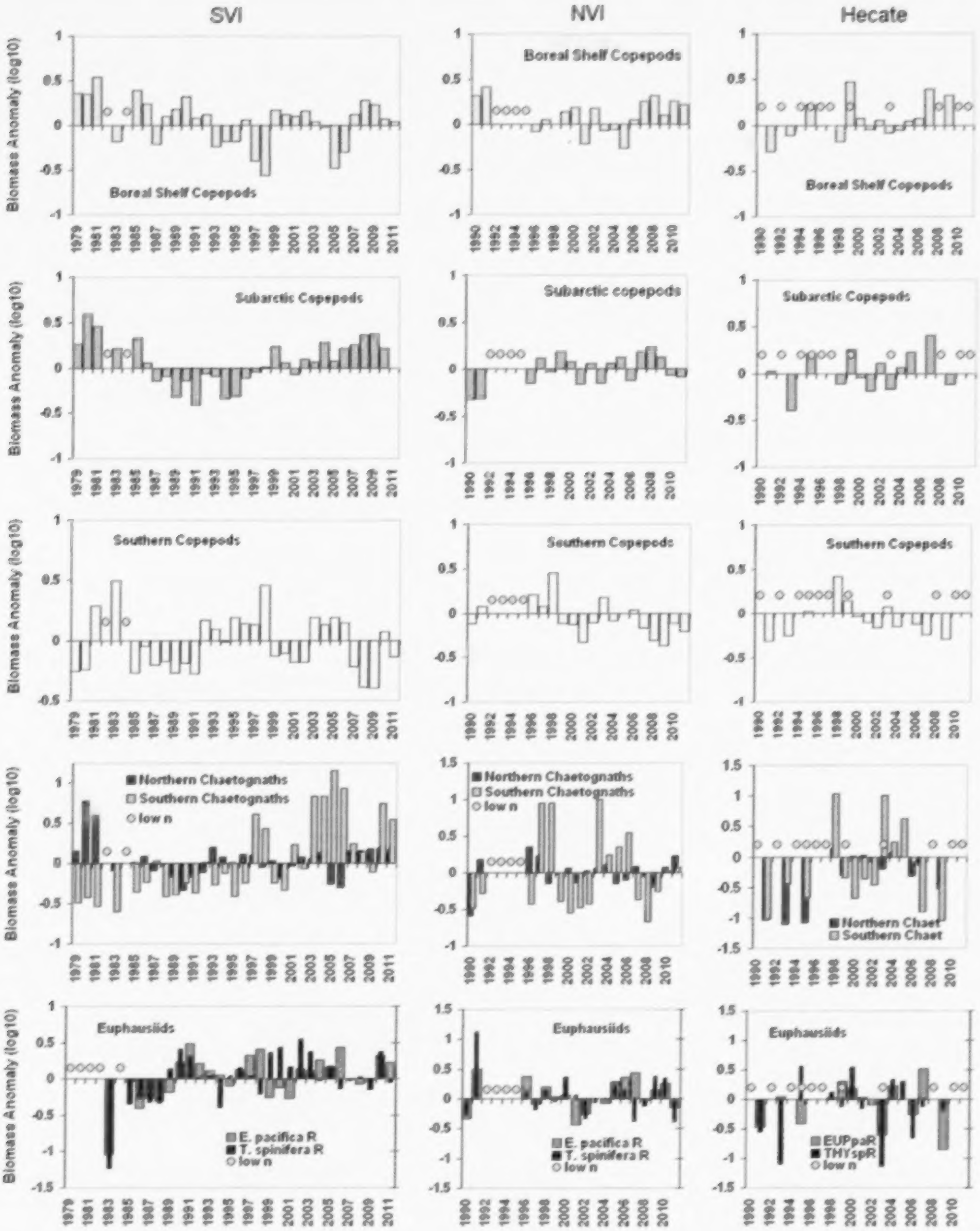


Figure 2. Zooplankton species-group anomaly time series (vs climatological baseline) for the SVI, NVI and Hecate regions shown in Fig 1. Bar graphs are annual log scale anomalies. Circles indicate years with no or very few samples from that region. Cool years favour endemic 'northern' taxa, warm years favour colonization by 'southern' taxa.

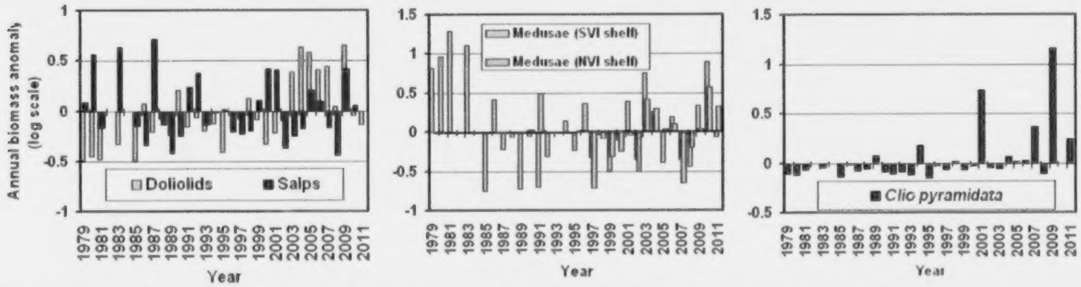


Figure 3. Anomaly time series for important gelatinous zooplankton off southern Vancouver Island. Left panel shows doliolids (genus Dolioletta*) and salps (genus* Salpa*) in the SVI region. Middle panel shows hydromedusae in the SVI and NVI regions. The large positive anomaly in 2010 consisted of* Mitrocoma. *Right panel shows the warm water pteropod* Clio pyramidata. *Their frequency and intensity of occurrence has increased dramatically since about 2000.*

The second change has been reduced similarity between the nearshore and adjoining offshore SVI subregions (Fig. 4). Most recent summers, including the cool years 2007-2009, have had positive anomalies of warm water taxa at locations seaward of the shelf break.

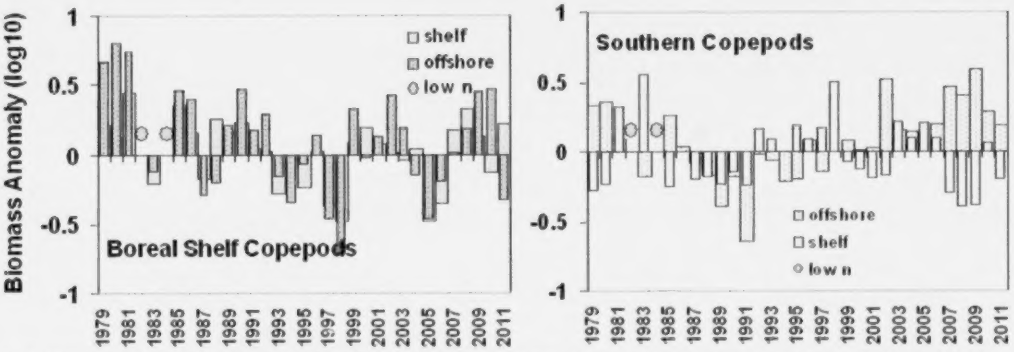


Figure 4. Comparison of anomaly time series from SVI shelf and offshore subregions. Before 2006, anomaly time series from these two subregions usually shared the same sign and had similar magnitudes. Since then, the offshore subregion has had positive summer anomalies of southern origin taxa even in cool years

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2.2.2 Euphausiids and west coast Vancouver Island fish production

Ron Tanasichuk, Fisheries and Oceans Canada

Zooplankton and euphausiids (krill) have been monitored in Barkley Sound since 1991. This information is being used to track their production variability and to provide observations of prey availability for stocks of herring and salmon along the west coast of Vancouver Island. The information presented here focuses on the euphausiid *Thysanoessa spinifera* because it is an important prey item for Pacific herring (Tanasichuk, *unpub material)*, and juvenile sockeye salmon (Tanasichuk and Routledge 2011).

Median larval biomass for *T. spinifera* (Fig. 1, top) varies seasonally, with lowest biomass in December to February and largest biomass in March to June. The seasonal larval biomass fluctuations reflect Tanasichuk's (1998) observation that *T. spinifera* spawns several times between early spring and late summer. The seasonal variability in larval biomass in 2011 was unusual and suggests that spawning began in May, much later than normal (March), and occurred in May and June only. Adult biomass typically has a less well defined spring and summer maximum (Fig. 1, bottom). Adult biomass early in the year, before May, represents over-wintering adults, and biomass later in the year reflects the production of new adults. The apparent inconsistency of low larval and higher adult biomasses explained successful recruitment in 2011 and the persistence and growth of the adults produced in 2010.

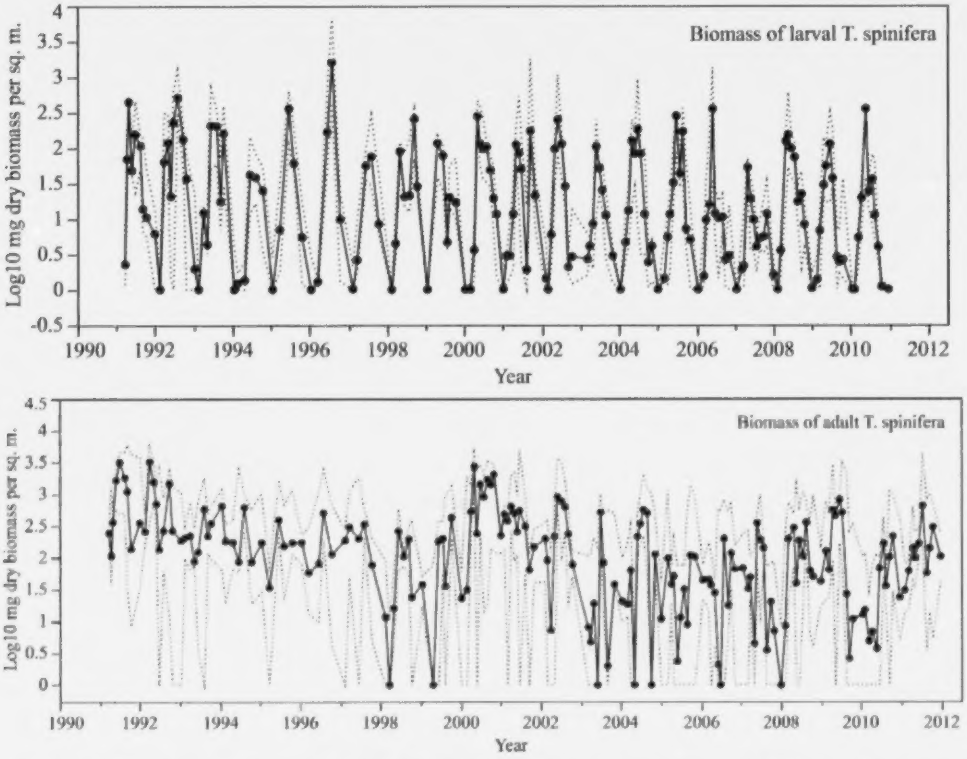

Figure. 1. The 1991-2011 time series of ***larval*** *(top, <10 mm long) and* ***adult*** *(bottom, > 9 mm long)* T. spinifera *biomass. Median larval and adult biomasses in 2011 were the lowest and at the median respectively in the time series. Larval biomass decreased by about 71% and adult biomass increased by about 300% from 2010. Closed circles – median biomass; dashed lines – minimum or maximum biomass.*

WCVI fish production variability

The fish populations whose production variability is studied are WCVI herring and Somass River (Great Central and Sproat lakes) sockeye. The results of analyses that describe the biological basis of biomass variability for herring, and return variability for sockeye salmon, are described in Tanasichuk (2010). These analyses tested the effects of prey, and also evaluated the influences of the populations themselves, competition and predation.

Pacific herring

The relatively high *T. spinifera* biomass in 2011 should result in increased herring recruitment (the production of new spawners), larger recruits and adult fish, and lower adult mortality, compared to 2010. Low hake biomass, as indicated by poor commercial catches, should contribute to the increase in recruitment.

Sockeye salmon

Return variability for sockeye salmon from Great Central and Sproat lakes was explained by variations in the biomass of an important prey item (3-5 mm *T. spinifera*) in May, when the juvenile salmon migrate through Barkley Sound to the continental shelf (see Tanasichuk and Routledge 2011). Regression equations describing *ln return* as a linear function of *ln T. spinifera* biomass are developed for each of the six age groups in each of the two lakes to forecast return for a given year. The regressions are statistically significant for 11 of these 12 lake-age groups with the regression being insignificant for a lake-age group that contributes few fish; the significant regressions explain between 41 and 75% of the variation in return.

The retrospective performance of the forecasts is shown in Fig. 2. The average absolute deviation of the forecasts was 384,000 fish and the absolute percent error was 55. The discrepancies for the 2010 and 2011 return years are of special note. In 2010, return for all lake age-groups was under-forecast; however, in 2011, returns were forecast accurately for 8 of the 12 groups although the total forecast was still low. The persistence of lake-age group-specific forecasting regressions, and the varied response of lake-age groups returning in 2011, reflect a meta-population structure which has been described recently for other sockeye (Schindler et al. 2010, Quinn et al. 2012).

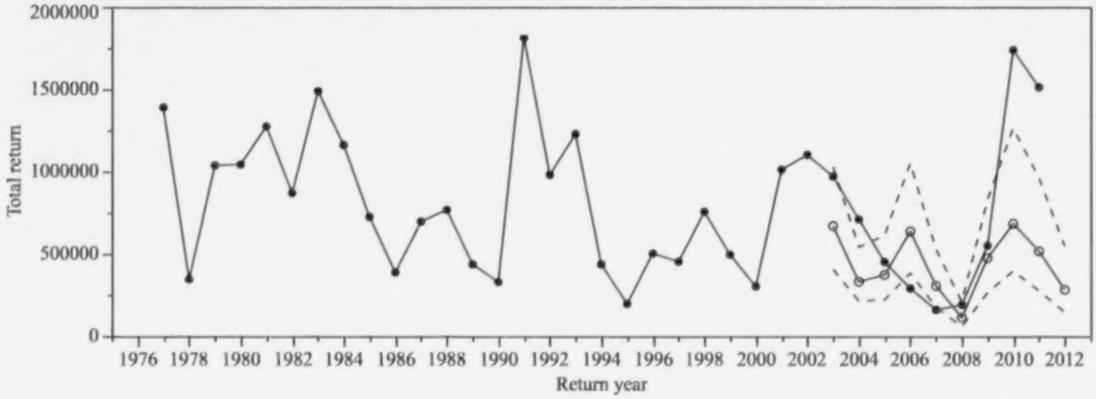

Figure 2. Observed (closed circles) and predicted (open circles) return of Somass River sockeye. Dashed lines show the lower and upper 50% confidence intervals for the forecasts.

The biomasses of 3-5 mm *T. spinifera* were progressively lower in May 2010 and 2011, which implies that the returns should be poor in 2013 and poorer in 2014.

Anticipated consequences

- Herring: increased recruitment, increased recruit size and adult growth, increased adult survival compared with 2010;
- Barkley Sound sockeye: low biomass of 3-5 mm *T. spinifera* in May 2011 should result in low returns of age 4 fish in 2013 and low returns of age 5 fish in 2014 relative to the time series.

References

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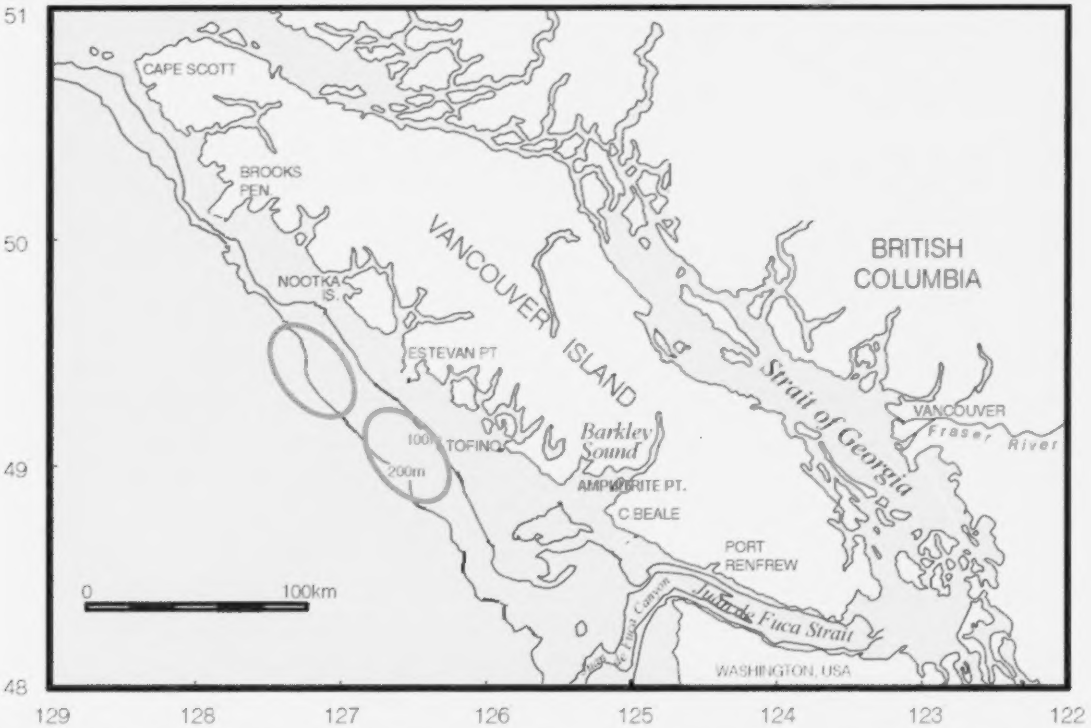
2.2.3 Small-mesh bottom-trawl surveys west of Vancouver Island and comparisons with commercial catches: update for 2011

R. Ian Perry, Jennifer Boldt, Caihong Fu, Dennis Rutherford, Ken Fong, Brenda Waddell, Fisheries & Oceans Canada

Bottom trawl surveys using a small-mesh net (targeting the smooth pink shrimp *Pandalus jordani*) have been conducted during May since 1973 in two regions off the west coast of Vancouver Island (Fig. 1).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CAPE SCOTT
BROOKS PEN.
NOOTKA IS.
VANCOUVER ISLAND
ESTEVAN PT
TOFINO
100m
200m
Barkley Sound
AMPHITRITE PT.
C BEALE
PORT RENFREW
Juan de Fuca Strait
WASHINGTON, USA
BRITISH COLUMBIA
Strait of Georgia
VANCOUVER
Fraser River
0
100km

*Figure 1. Map showing the two main shrimp (*Pandalus jordani*) fishing grounds off Vancouver Island (red ovals) considered in this report. The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and southern red ovals, respectively.*

Surveys in May 2011 found the biomass of *Pandalus jordani* shrimp off central Vancouver Island had decreased from high abundances in 2009 and 2010 (Fig. 2). This decrease appears related to warmer waters off the west coast of Vancouver Island in spring 2009 during the larval stages of the shrimp (this species has a 2-yr time lag from hatch to recruitment at age 2). Comparisons of shrimp biomass and sea surface temperatures in this region during these surveys indicate a negative relationship: shrimp biomass is generally low when spring temperatures exceeded 11°C two years previously. Experimental studies suggest that the optimal temperature range for survival of larvae of this species of shrimp is 8.0°C to 11.0°C (Rothlisberg 1979). Biomass trends of key flatfish indicator species all decreased in 2011 (Fig. 2), whereas the biomass of the "cold water indicator" species walleye pollock increased (Fig. 2).

This small-mesh bottom trawl survey was designed to target smooth pink shrimp on the shrimp fishing grounds in a relatively small area off the west coast of Vancouver Island (Fig. 1). Other taxa caught along with smooth pink shrimp may, or may not, be sampled quantitatively, depending on whether these other taxa are highly mobile in and out of the survey area or are highly patchy in their distribution. An autocorrelation analysis suggests that of the 36 taxa regularly sampled by this survey, 16 of them appear to be well-sampled by this survey. Of those species shown in Fig. 2, all are well-sampled by this survey gear except for spiny dogfish and Pacific hake.

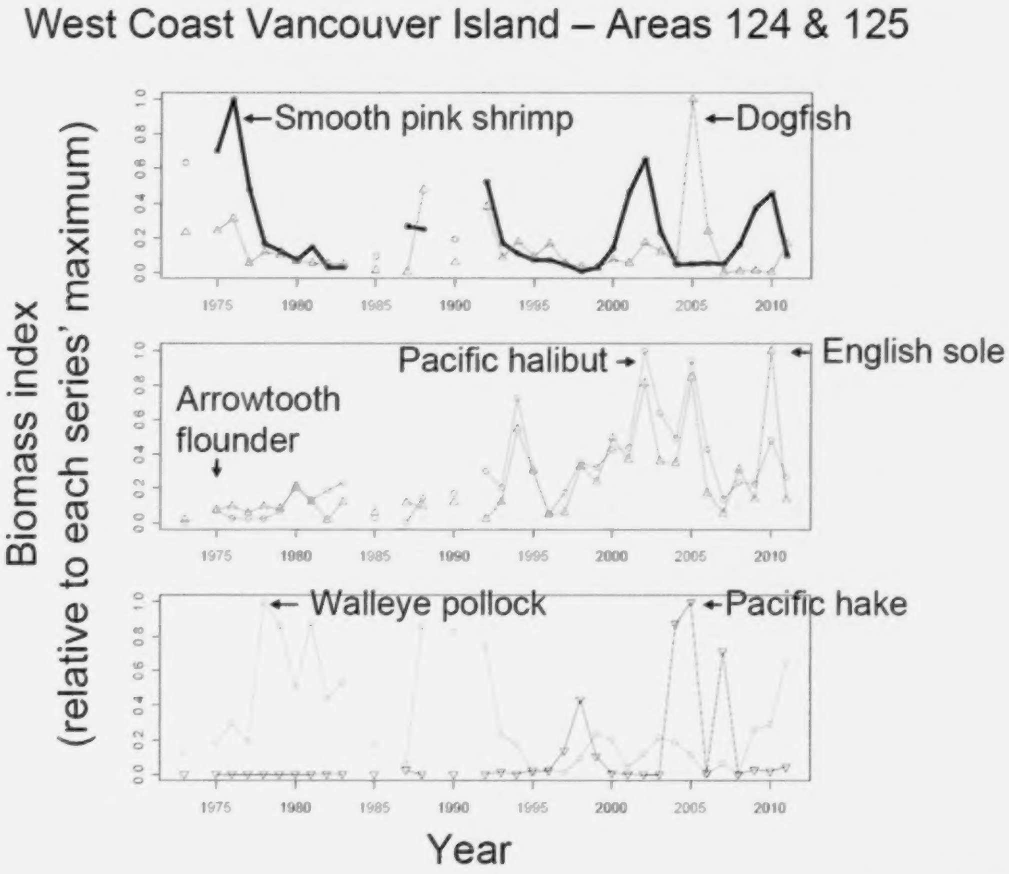


Figure 2. Time series of normalised (to maximum biomass) survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock. Sampling was conducted in May of each year.

Data from this survey are being used in a global analysis of marine ecosystems (www.indiseas.org). This analysis compares data and trends from the commercial fishery off the middle-west coast of Vancouver Island with data from the above fishery-independent small-mesh bottom-trawl surveys. Total landings of the commercial catch since 1980 (Fig. 3) show an increasing trend, with variability largely driven by environmentally-mediated migrations of Pacific hake from the south into Canadian waters. Similarly, the mean trophic level defined from this commercial catch shows an increasing trend (Fig. 4), whereas the mean trophic level calculated from the fishery-independent trawl surveys shows no trend (Fig. 5). These results are interpreted to indicate no "fishing down the food web" of this ecosystem over this time period.

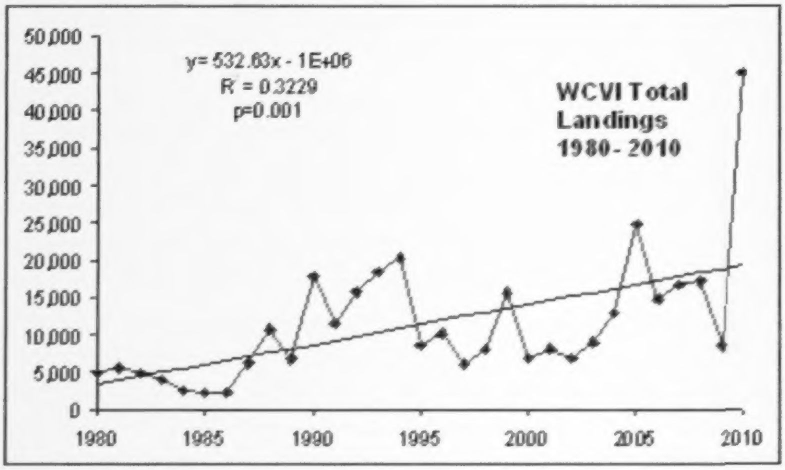


Figure 3. Total landings of the commercial catch (MT) in Statistical Areas 124 and 125 off the west coast of Vancouver Island.

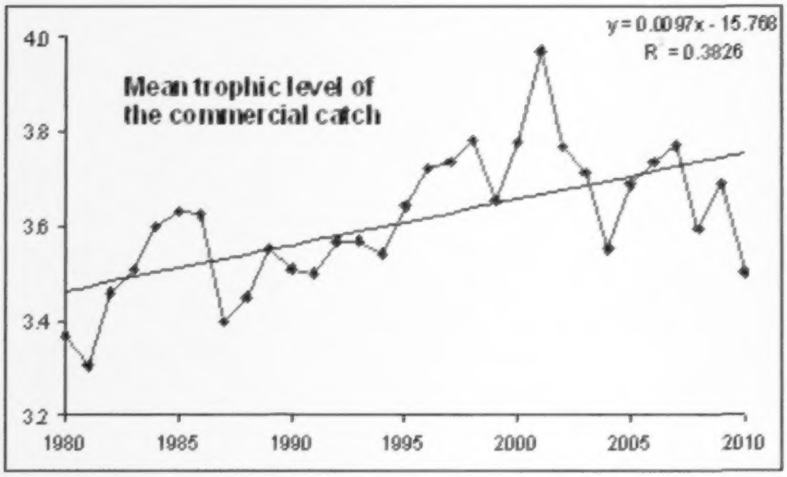


Figure 4. Mean trophic level (TL) of the commercial catch in Statistical Areas 124 and 125 off the west coast of Vancouver Island. Y-axis indicates the trophic level (for reference: typically TL=2 represents herbivores, TL=3 represents carnivores, TL=4 and 5, apex predators). Same taxa as Fig. 3.

Taxa included in Figs. 3 and 4: American Shad; Arrow tooth flounder; Black, Canary, China, Copper, Darkblotched, Greenstriped, Longsprine thornyhead, Quillback, Redbanded, Redstripe, Rosethorn, Rougheye, Sharpchin, Shortraker, Shiprtspine thornyhead, Silvergray, Splitnose, Widow, Yelloweye, Yellowmouth, Yellowtail rockfish; Bocaccio; Crab; Dover, English, Flathead, Petrale, Rex, Slender, Southern rock sole; Eelpouts; Eulachon; Flatfishes; Giant Pacific Octopus; Grenadiers; Lingcod; Mackerel; Pacific cod; Pacific hake; Pacific halibut; Pacific herring; Pacific sardine; Pacific tomcod; Poachers; Pacific Ocean perch; Pricklebacks; Ratfish; Sablefish; Salmonids; Sanddabs; Sculpins; Sharks; Shiner perch; Shrimp; Skates; Spiny dogfish; Pandalid shrimp; Squid; Walleye pollock.

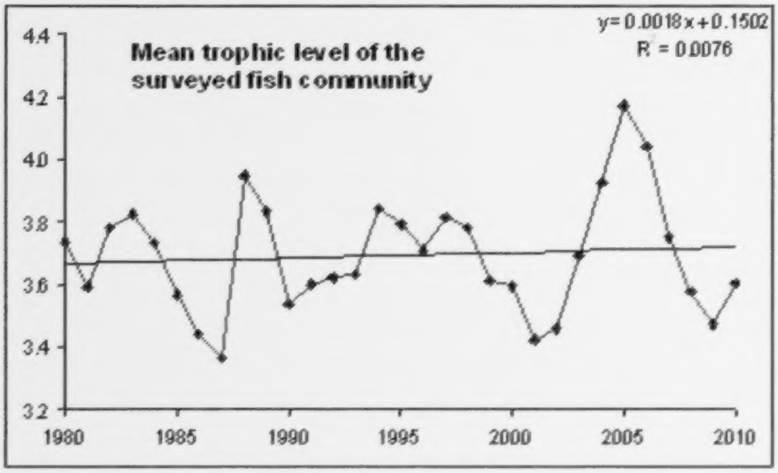


Figure 5. Mean trophic level of the fish community surveyed by the fishery-independent small-mesh bottom-trawl gear in Statistical Areas 124 and 125 off the west coast of Vancouver Island. Typical trophic levels are as described for Fig. 4.

Taxa included in Fig. 5: American Shad, Arrowtooth flounder; Canary and Yellowtail rockfish; Dover, Southern rock, Rex, Slender, English, and Flathead sole; Eelpouts; Eulachon; Giant Pacific Octopus; Lingcod; Pacific cod; Pacific hake; Pacific halibut; Pacific herring; Pacific tomcod; Petrale sole; Pricklebacks; Ratfish; Sablefish; Sanddabs; Sculpins; Shiner perch; Skates; Spiny dogfish; Pandalid shrimp; Walleye pollock.

Reference

Rothlisberg, P. 1979. Combined effects of temperature and salinity on the survival and growth of the larvae of *Pandalus jordani* (Decapoda: Pandalidae). *Marine Biology*. 54: 125-134

2.2.4 Multi-species groundfish bottom trawl surveys in Hecate Strait/Dixon Entrance and Queen Charlotte Sound: Update for 2011

Greg Workman and Kate Rutherford, Fisheries and Oceans Canada

The groundfish section at the Pacific Biological Station initiated a series of multi-species bottom trawl surveys in the summer of 2003. The program has since grown to include four biennial specific surveys, with surveys repeated in the same months in each region. In 2011 the program completed two surveys: one in late May to June in Hecate Strait and Dixon Entrance (HS/DE) and one in July in Queen Charlotte Sound (QCS). Surveys follow a random depth stratified design in which 2x2 km blocks are selected at random within depth strata and one bottom trawl set is made in each block if possible. Catches are fully enumerated and biologically sampled. The primary output from these surveys is a table of biomass indices.

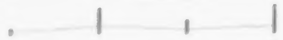
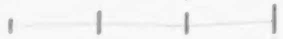
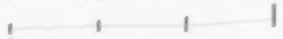
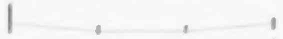
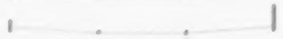
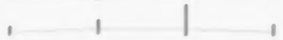
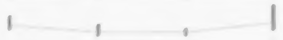
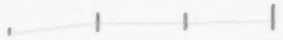
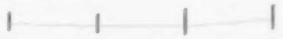
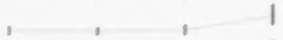
In addition to the information collected for the production of biomass indices, a net-mounted CTD is used on each set to collect temperature, salinity and dissolved oxygen data. Trends in the oceanographic values have been compared year-to-year, but at this point there has not been an in-depth examination of the possible relationships with catch rates or changes in fish size.

Hecate Strait

In Hecate Strait, biomass indices increased for 25 of 28 species between 2009 and 2011 (Table 1). While these data have not been statistically evaluated, the positive trend in such an overwhelming proportion of the species indicates the pattern is likely real and we therefore comment on several groups. An increase in abundance of Spotted Ratfish is consistent with surveys in other areas of the BC coast. Spotted Ratfish are one of the most frequently discarded species in the BC bottom trawl fishery yet despite the presumed high discard mortality the species still appears to be increasing in abundance, perhaps reflecting a shift in ecosystem structure. Another noteworthy observation is the dip in abundance of Arrowtooth Flounder observed in the 2007 survey. This dip coincides with a major increase in directed effort and landings of Arrowtooth Flounder in response to a new market in 2006; that market has since disappeared. The dip observed in 2007 possibly reflects localized short term depletion, as a significant proportion of the Arrowtooth Flounder landed in 2006 came from Hecate Strait. Other generally increasing trends include those of Kelp Greenling, Greenstriped Rockfish, Pacific Herring, and Petrale Sole. Walleye Pollock on the other hand appears to have been declining in abundance throughout the time series.

Dissolved oxygen levels in 2011 were similar to 2009 throughout the depth range, and lower than in 2007 between 20 and 200 m (Fig. 1, top). Water temperatures at depth (Fig. 1, middle) in 2011 were warmer than 2009 down to about 150 m and then similar for the rest of the depth range. Temperatures in 2005 were the highest; 2007, 2009 and 2011 temperatures were similar (Fig. 1, middle). Salinity levels (Fig. 1, bottom) in 2011 were lower than observed in 2009 down to about 100 m and similar at other depths. Salinities in 2007 were generally lower than in 2009 and 2011. The conditions observed in Hecate Strait in 2011 were more similar to 2009 with lower observed dissolved oxygen, lower temperatures and higher salinities at depth than those seen in 2007; this is likely reflective of increased upwelling or increasing hypoxia in the region.

Table 1 Biomass indices from the 2011 Hecate Strait groundfish multi-species bottom trawl survey. Indices are in metric tonnes and are relative, not absolute, indices of biomass. The plots represent the trend since the start of the time series in 2005; blue vertical bars represent the variance around the index.

Species		2005	2007	2009	2011
Arrowtooth flounder		14,777.0	6,599.3	12,728.5	15,416.4
Big skate		758.7	785.9	376.1	1,256.8
Butter sole		68.9	206.0	154.3	233.4
Dover sole		3,101.0	2,664.6	2,049.2	4,139.5
English sole		2,735.9	2,904.1	2,733.7	3,152.7
Eulachon		40.2	17.7	97.4	127.3
Flathead sole		511.9	306.0	325.2	499.0
Greenstriped rockfish		4.4	4.3	10.2	21.3
Kelp greenling		39.9	52.1	62.5	72.8
Lingcod		185.9	235.0	238.1	362.3
Longnose skate		399.7	208.8	212.0	386.7
N. Pacific Spiny Dogfish		3,969.0	1,269.1	992.8	5,121.1
Pacific cod		1,886.6	568.6	2,424.5	1,822.0
Pacific halibut		1,934.6	1,023.5	1,670.8	3,350.1
Pacific herring		150.9	88.5	141.4	323.4
Pacific ocean perch		337.6	454.0	498.2	313.7
Petrale sole		156.8	265.6	222.6	387.9
Quillback rockfish		203.3	405.2	180.9	381.9
Redbanded rockfish		638.6	340.8	311.8	744.7
Rex sole		2,180.1	2,354.3	2,211.1	2,680.1
Sand sole		519.6	358.1	534.7	534.7
Shortspine thornyhead		234.3	343.4	164.3	290.4
Silvergray rockfish		417.4	256.5	590.4	600.0
Slender sole		17.6	39.4	38.5	45.1
Southern rock sole		2,026.0	1,927.5	1,840.3	2,277.9
Spotted ratfish		6,188.9	5,955.9	6,794.3	15,026.9
Sturgeon poacher		1.3	2.7	5.4	9.9
Walleye pollock		1,723.0	1,371.7	1,016.2	1,060.7

A preliminary comparison of median depth of capture for 28 species of groundfish is presented in Fig. 2. The shoaling of species observed between the 2009 and 2007 surveys was not evident in the 2011 survey; in fact median depth of capture was similar across species between 2007 and 2011 despite the lower dissolved oxygen (DO) levels observed in 2011. Previous authors reported a general shoaling of species depth distributions and hypothesised that this might be related to declines in measured DO at depth, implying a loss of habitat for demersal groundfish species. Based on the cursory analysis undertaken here, this year's observations do not appear consistent with that hypothesis, at least in Hecate Strait.

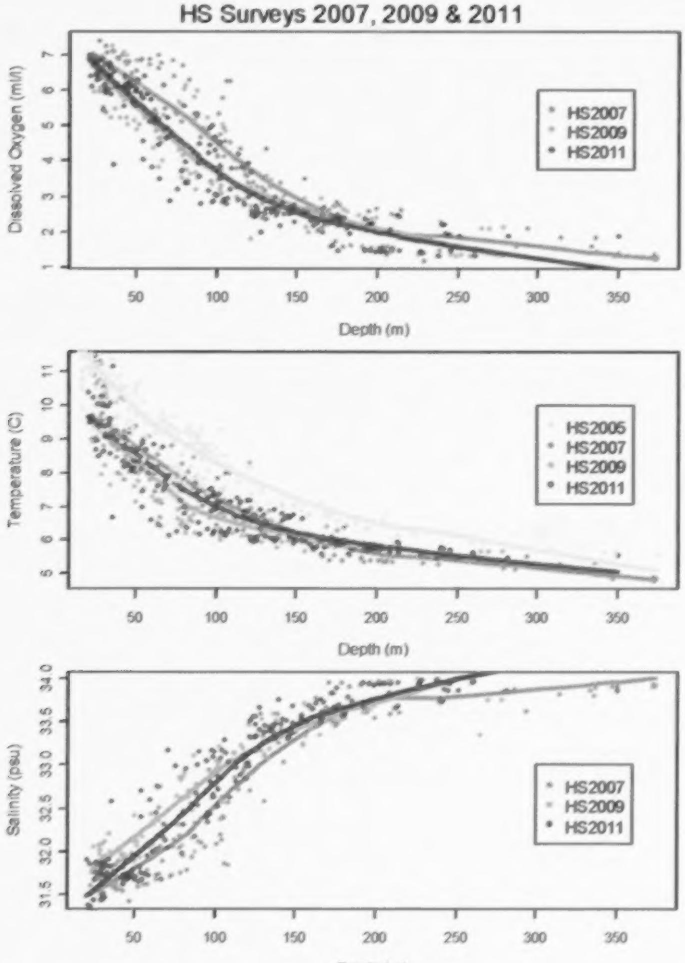


Figure 1. Comparison of dissolved oxygen, temperature and salinity with depth for the 2007, 2009 and 2011 Hecate Strait groundfish multi-species bottom trawl surveys.

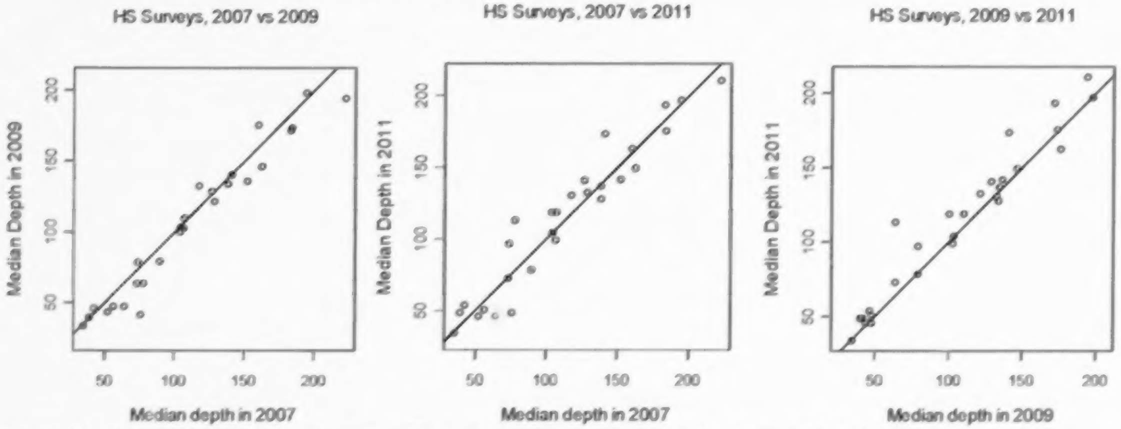
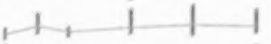


Figure 2. Comparison of median depth (m) for 28 groundfish species in the Hecate Strait groundfish multi-species bottom trawl surveys in 2007, 2009 and 2011.

Queen Charlotte Sound

In Queen Charlotte Sound, biomass indices for 18 of 25 species increased from 2009 to 2011 (Table 2), similar to the trend reported above for Hecate Strait, although Queen Charlotte Sound catches generally were more variable. This may reflect a change in abundance or possibly changes in selectivity, catchability, or fish behaviour. As was noted above for Hecate Strait, there was a decrease in the abundance index for Arrowtooth Flounder in 2007 with subsequent recovery, the explanation is the same; the observation is reflective of the increased pressure put on Arrowtooth Flounder in 2006. Also notable is the levelling off of the declining trend for Pacific Ocean Perch which may be reflective of reductions in annual catches beginning in 2008 and reduced TACs in 2011 resulting from an updated assessment in 2010. As was noted in Hecate Strait, it appears that Greenstriped Rockfish and Petrale Sole may be increasing in abundance; most other abundance time series appear flat or equivocal.

Table 2: Biomass indices from the 2003 - 2011 Queen Charlotte Sound groundfish multi-species bottom trawl surveys. Indices are in metric tonnes and are relative, not absolute, indices of biomass. The plots represent the trend since inception of the time series in 2003; blue vertical bars represent the variance around the index.

Species		**2003**	**2004**	**2005**	**2007**	**2009**	**2011**
Arrowtooth flounder		5,789.2	11,927.7	13,668.2	7,388.2	9,366.8	13,370.1
Blackbelly eelpout		51.3	149.4	273.9	40.4	58.7	111.2
Curlfin sole		13.7	17.9	27.3	13.6	13.0	19.0
Dover sole		1,805.3	2,537.1	1,847.7	867.6	1,021.6	1,665.0
English sole		1,104.4	1,152.5	827.8	341.9	547.5	818.2
Flathead sole		540.8	1,047.6	921.7	329.4	261.8	359.0
Greenstriped rockfish		110.7	234.1	126.9	130.7	160.3	233.6
Lingcod		697.8	681.8	512.9	549.6	699.3	662.0
Longnose skate		477.7	536.8	561.4	275.5	290.6	370.8
Pacific cod		808.1	1,633.7	1,517.2	428.6	564.5	1,023.3
Pacific hake		1,153.0	5,791.6	5,558.2	3,166.4	2,257.3	1,248.6
Pacific halibut		790.3	976.7	1,105.4	1,262.7	955.1	630.0
Pacific ocean perch		22,475.6	16,773.7	14,386.9	10,535.0	12,240.2	12,431.6
Pacific sanddab		1,177.5	923.7	350.2	180.7	153.9	226.5
Petrale sole		293.1	392.2	394.4	203.9	295.0	480.0
Redbanded rockfish		868.0	542.8	1,218.2	888.5	869.7	831.2
Rex sole		2,351.9	2,257.7	1,952.6	909.0	1,082.1	1,579.9
Rosethorn rockfish		72.1	86.2	69.1	54.7	37.6	68.3
Sablefish		1,112.6	1,824.0	1,068.2	827.0	932.0	767.7
Sandpaper skate		21.2	13.4	16.3	15.2	14.0	10.5
Shortspine thornyhead		944.1	1,202.0	890.5	487.9	767.9	812.1
Silvergray rockfish		2,318.2	3,901.6	2,759.8	3,577.1	3,971.4	3,886.0
Slender sole		81.4	79.7	58.3	32.6	39.6	92.4
Southern rock sole		709.9	1,461.7	983.9	625.6	757.0	912.2
Yellowmouth rockfish		1,658.6	3,859.5	1,614.1	1,425.1	2,607.7	2,646.7

At depths less than 100 m, the dissolved oxygen levels (Fig. 3, top) in 2011 were higher than in 2009 but at deeper depths dissolved oxygen levels were lower than in 2007 or 2009. Water temperatures at depth (Fig. 3, middle) in 2011 were warmer than in 2009 down to about 250 m and colder in depths greater than about 350 m. Temperatures in 2011 were also generally warmer than in 2007. Salinity levels (Fig. 3, bottom) in 2011 were lower than in 2009 down to about 125 m and then quite similar for the rest of the depth range. This may indicate a lower degree of mixing of the water column or a slight decrease in oxygen concentration at depths below 100 m in 2011.

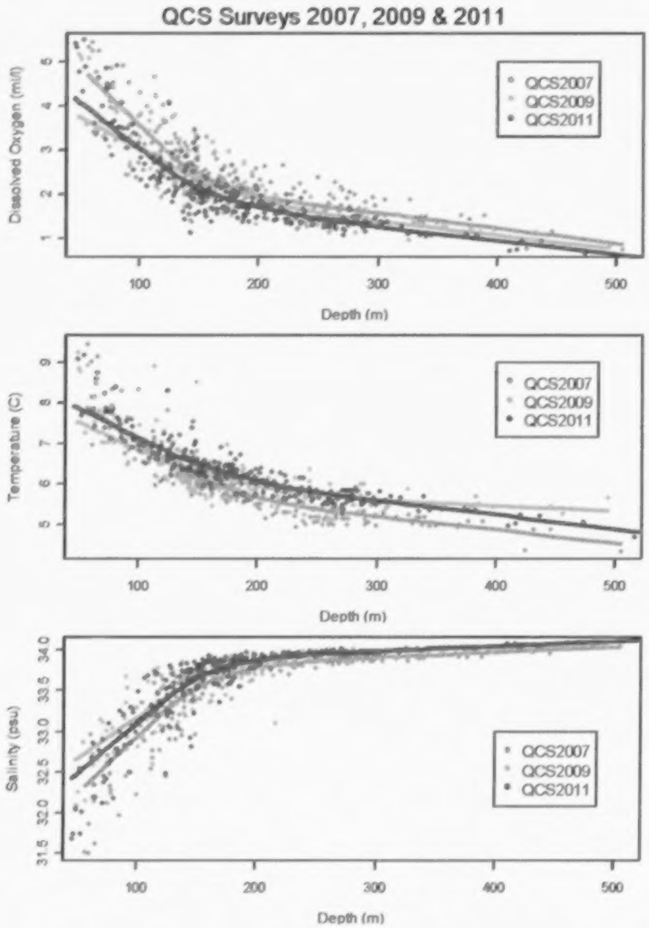


Figure 3. Comparison of dissolved oxygen, temperature and salinity with depth for the 2007, 2009 and 2011 Queen Charlotte Sound groundfish multi-species bottom trawl surveys.

A comparison of median depth of capture for 25 species of groundfish is presented in Fig. 4. With the exception of species at less than 100 m the median depths of species examined were deeper in 2009 and 2011 than in 2007. There appears to be a fairly even split between 2009 and 2011. As was noted above for Hecate Strait, other researchers have hypothesized that shifts in depth distributions of groundfish and reduced oxygen are correlated; however, these years of observations do not appear to be consistent with that hypothesis. Despite slightly lower observed oxygen levels at depth, most species were found at greater depths in 2011 than in 2007 when oxygen levels were in higher.

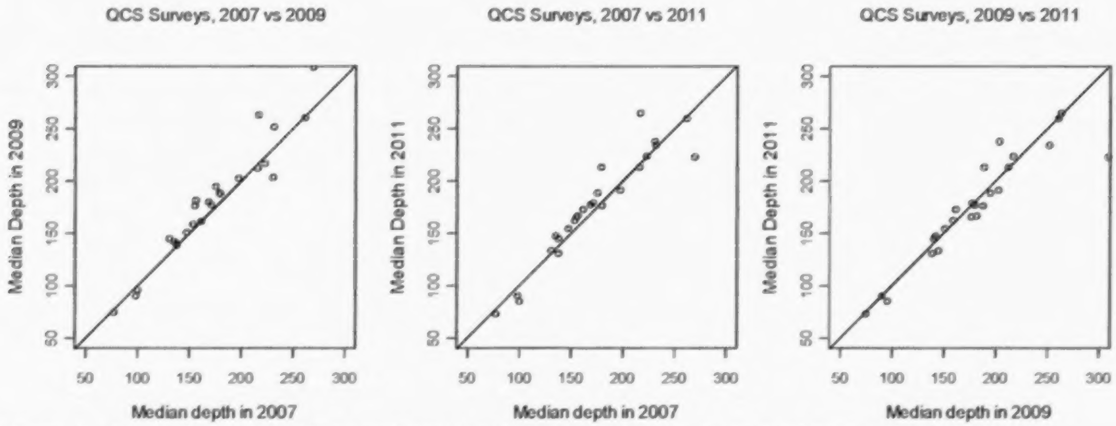


Figure 4. Comparison of median depth (m) for 28 groundfish species in the Queen Charlotte Sound groundfish multi-species bottom trawl surveys in 2007, 2009 and 2011.

Observed in-situ oceanographic conditions were different between Hecate Strait and Queen Charlotte Sound in 2011. Queen Charlotte Sound was generally warmer and more saline between about 100 m and 300 m depth than in previous years, while Hecate Strait was cooler and more saline between the surface and about 200 m. Both had lower dissolved oxygen levels in these depth ranges. These differences between areas can as easily be attributed to timing though, with the Hecate Strait survey occurring a full month ahead of the Queen Charlotte Sound Survey. Despite the reductions in oxygen at depth, most species were not only more abundant in 2011 but also found at deeper (more hypoxic) depths. These observations appear inconsistent with the hypothesis that hypoxic conditions are leading to a general shoaling of groundfish and a reduction in their available habitat. However, a more fulsome analysis incorporating additional data on commercial fishery depth of capture as well other oceanographic data sets is required to fully assess the relationship between species depth distribution and levels of dissolved oxygen.

2.2.5 Herring

Jennifer Boldt, Jaclyn Cleary, Jake Schweigert , Kristen Daniel, Charles Fort, Ron Tanasichuk, Matt Thompson, Fisheries and Ocean Canada

Description of indices

Model estimates of Pacific herring biomass, based on commercial and test fishery biological samples (age, length, weight, sex, etc.), herring spawn dive survey data, and commercial harvest data, provide indices of herring population trends for five major fishing stocks: Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), Prince Rupert District (PRD), Haida Gwaii (HG; previously referred to as the Queen Charlotte Islands stock), and the central coast (CC), and two minor stocks (Area 2W and Area 27) (Cleary and Schweigert 2012; DFO 2011; Fig. 1).

In 2011, a new integrated, statistical, catch-age model was used for the Pacific herring assessment, resulting in higher biomass estimates for the entire time series (DFO 2011); therefore, time series of biomass estimates differ from those in previous years' State of Ocean assessments, but the temporal biomass trends are similar. A second index is an annual, offshore survey that provides an index of recruitment to the WCVI and the SOG herring stocks, based on the catch-per-unit-effort (CPUE)-weighted proportion of age-3 pre-recruit herring in the common summer feeding area off the WCVI (both these stocks occupy the WCVI region in summer). A third index of herring recruitment trends is obtained with the juvenile herring survey conducted annually in the SOG and CC. These three indices provide information on population trends and inform Fisheries and Oceans Canada science advice regarding catch recommendations.

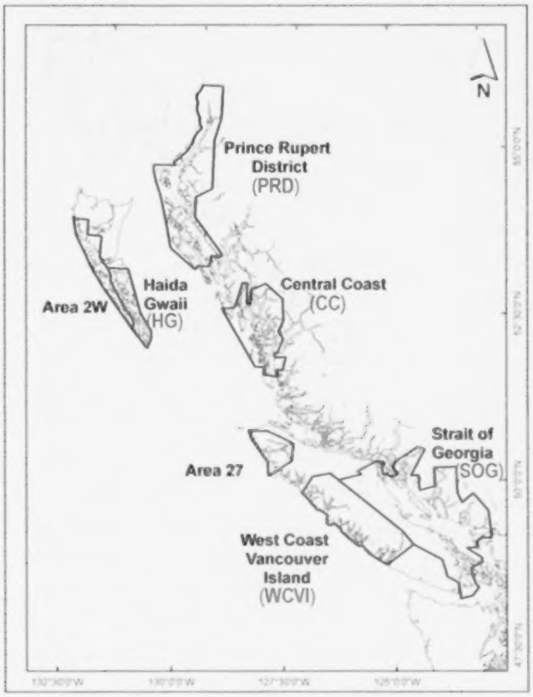


Figure 1. Location of the five major (Strait of Georgia, west coast of Vancouver Island, Prince Rupert, Haida Gwaii, and the Central Coast) and two minor (Area 2W and Area 27) Pacific herring fishing stocks in British Columbia.

Status and trends

West Coast Vancouver Island (WCVI): Herring biomass off the WCVI has experienced continual declines since the late 1980s. Current low levels of biomass are consistent with levels observed in the late 1960s following the reduction fishery (1951-1968), despite the absence of commercial fishing for the majority of the past decade (Cleary and Schweigert 2012, DFO 2011; Fig. 2).

Estimates of biomass are higher for 2011 than 2010 due to structural changes to the assessment model, however time series trends are the same. Biomass estimates in 2011 are similar to low levels observed since 2006, and in 2011 (Fig. 2) are slightly above the fishery threshold (14,894 tonnes). Since about 1977, the recruitment of herring off the WCVI has been generally poor, interspersed with a few good year-classes (Fig. 3). Recruitment in 2011 was average and results from the summer 2011 off-shore trawl survey indicate poor recruitment for 2012. There has been little evidence of stock recovery in this area, despite the absence of commercial fishing since 2006. WCVI herring weight-at-age has declined since the mid-1970s or mid-1980s (Fig. 4).

Strait of Georgia (SOG)

The biomass of herring in the SOG reached near historic high levels from 2002-2004 at over 100,000 tonnes (Cleary and Schweigert 2012, DFO 2011; Fig. 2). Current spawning biomass is still relatively high and is well above the fishery threshold (35,013 tonnes). Since 1995, recruitment to this stock has been average or good except in 2008 and 2010 (Fig. 3). In 2011, recruitment was good and both the summer off-shore trawl survey and the juvenile herring survey indicate good recruitment for 2012. SOG herring weight-at-age has declined since the mid-1970s (Fig. 4).

Prince Rupert (PRD), Haida Gwaii (HG), and Central Coast (CC)

Exploitable herring biomass in the PNCIMA region represents a combination of migratory stocks from the HG, PRD and CC areas (Cleary and Schweigert 20120, DFO 2011). Herring biomass in HG (Fig. 2) was depressed in 2006-2010 and has shown a small increase in 2011; however, it is still below the fishery threshold (10,436 tonnes). The biomass in the CC has been low since 2007 and is currently below the fishery threshold (15,600 tonnes). The biomass in PRD has remained relatively stable (Fig. 2), and is above the fishery threshold (19,641 tonnes). PRD, HG, and CC herring weight-at-age has declined since the mid-1970s (Fig. 4).

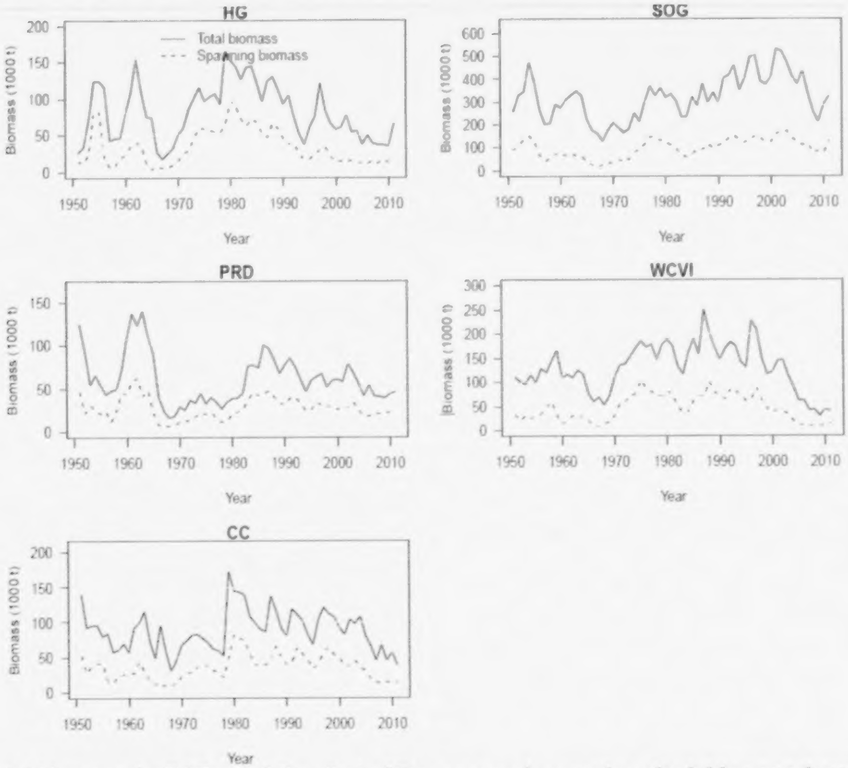


Figure 2. Total biomass (solid line) at the start of the year and spawning stock biomass (post-fishery; dashed line) of Pacific herring in the five major stock areas in British Columbia.

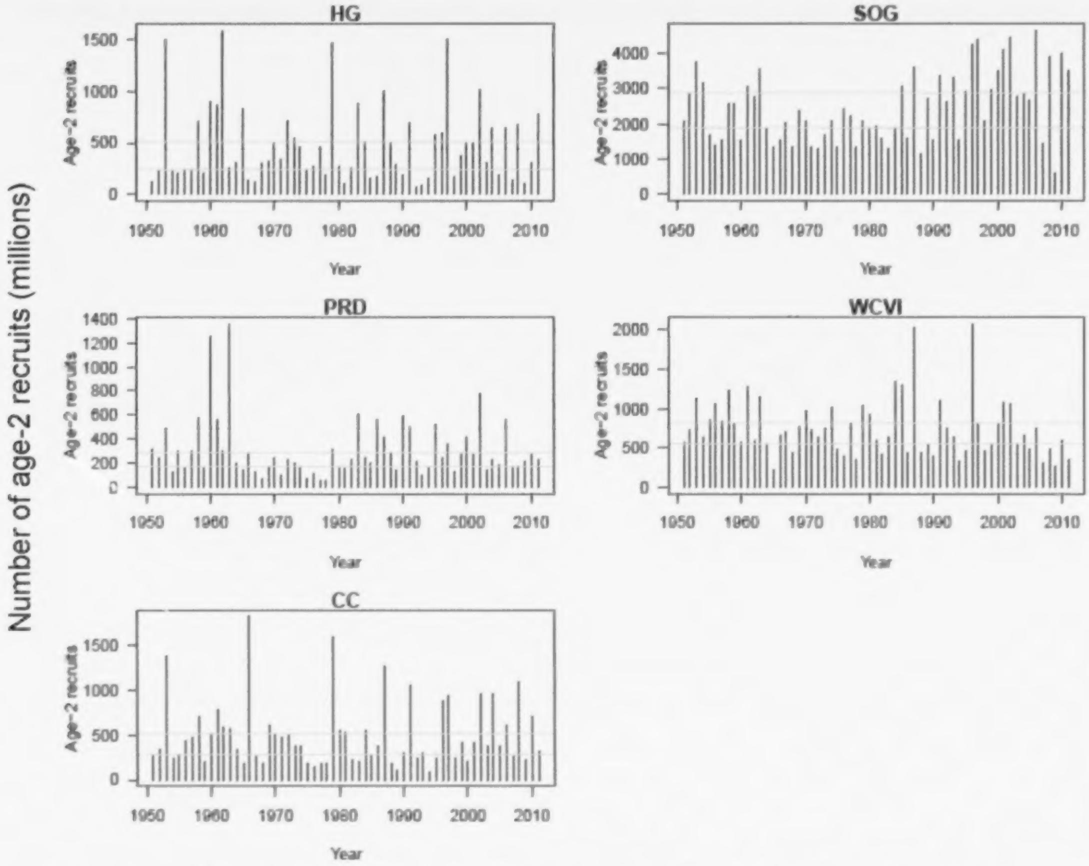


Figure 3. Estimated number of Pacific herring age-2 recruits (millions) for the five major fishing stocks in British Columbia. Horizontal lines delineate the lower, middle, and upper third of historical recruitment estimates. Note: age-3 abundance is usually reported, however, trends are similar.

Factors causing those trends

Despite a precautionary harvest policy for herring that has been in place since 1986, the biomass of all five major fishing stocks has declined during the past decade (Schweigert et al. 2009). This suggests that factors other than fishing are influencing herring population trends. Changes in food supply and quality, predator abundance, and competition are factors that could affect trends in herring biomass and weight-at-age (Schweigert et al. 2010; Tanasichuk 2012 and Hay et al. 2012, elsewhere in this research document)

Pacific herring are zooplanktivorous, consuming primarily euphausiids (krill) and some copepods (Wailes 1936). Changes in ocean conditions, such as temperature or currents, could affect the amount and types of prey available. For example, a northerly current direction could result in the presence of California current waters off the WCVI, bringing California Current zooplankton species that have a lower energetic value, creating poorer feeding conditions for herring (Schweigert et al. 2010, Mackas et al. 2004). In addition, Tanasichuk (2012, elsewhere in this research document) relates WCVI herring recruitment to the biomass of euphausiids.

There are a wide variety of herring predators, including Pacific hake, lingcod, spiny dogfish, Pacific cod, sablefish, arrowtooth flounder, Pacific halibut, Steller sea lions, northern fur seals, harbour seals, California sea lions, and humpback whales (Schweigert et al. 2010). Off the

WCVI, fish predator abundance has decreased in recent years, while the abundance of most marine mammal predators has increased (Olesiuk 2008, Olesiuk et al. 1990). This has resulted in a relatively stable or slightly decreasing trend in the amount of WCVI herring consumed by predators since 1973 (Schweigert et al. 2010). Although a significant proportion of the herring population could be cropped annually by predation, natural mortality of WCVI herring was not found to be directly attributable to predation; (Schweigert et al. 2010). Herring recruitment, however, has been correlated with piscivorous hake biomass (piscivorous hake are those hake that are large enough to consume herring), suggesting predation may be an important factor influencing WCVI herring recruitment (Tanasichuk 2012, elsewhere in this research document).

Competition may also be a factor affecting herring population trends. Since the late 1990s, a substantial component of the Pacific sardine population off the west coast of North America has migrated into Canadian waters annually (Schweigert et al. 2009). Pacific sardine are primarily phytoplanktivores, but also consume some of the same prey as herring (McFarlane et al. 2005). Reduced survival of adult herring is most pronounced in areas exposed to offshore influences (WCVI, HG, and to a lesser extend CC; Schweigert et al. 2010), where sardine migrate. The large increases in Pacific sardine in the early 1990s to 2000s in Canadian waters may have increased competition for food with herring, and/or attracted predators (Schweigert et al. 2010).

Implications of those trends

Pacific herring comprise an important component of commercial fisheries in British Columbia. Estimated biomass of herring relative to the commercial fishery threshold has implications for herring fisheries. The biomass forecasts for SOG and PRD herring are above fishery thresholds; therefore these areas are open to commercial harvest for the 2011/12 season (DFO 2011). Following the herring harvest control rule, the maximum available harvest is based on a 20% harvest rate of the mature herring biomass (Cleary and Schweigert 2012). Biomass estimates for HG, CC and WCVI stocks all remain at relatively low stock abundance levels. Biomass forecasts for HG and CC stocks are below the fishery threshold and commercial harvest is not recommended for 2011/12 in these areas. Fisheries management have approved a small spawn-on-kelp harvest for the WCVI (biomass is slightly above the fishery threshold). The long-term recommendation for management of HG, CC and WCVI stocks is the development of stock rebuilding strategies.

Trends in herring biomass have implications for herring predators, such as fish, marine mammals and seabirds. The relative importance of herring in each predator's diet varies; however, herring may represent up to 88% of lingcod diet (Pearsall and Fargo 2007), 40% of Pacific cod and Pacific halibut diets (Ware and McFarlane 1986), and 35% - 45% of pinniped diets (Olesiuk et al. 1990, Womble and Sigler 2006, Trites et al. 2007, Olesiuk 2008). Depending on the level of diet specialization and ability to switch to alternate prey, herring abundance and condition may affect predators' growth and abundance. Diet data time series of animals in this ecosystem would improve our ability to examine temporal trends in predator-prey interactions and implications of those trends.

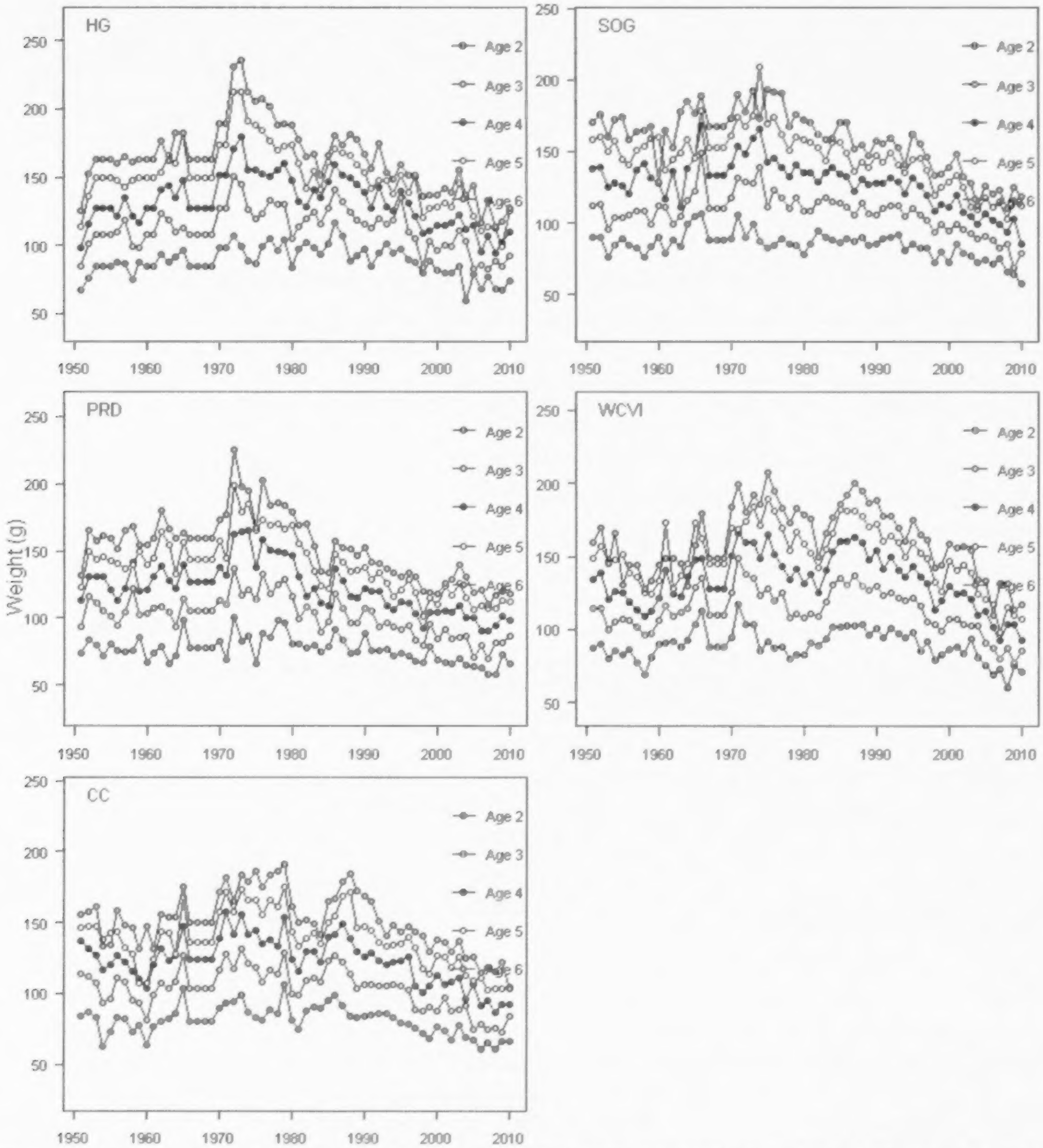


Figure 4. Weight-at-age (ages 2-6) of Pacific herring in the five major fishing stocks in British Columbia (1951-2010).

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2.2.6 Decrease in herring size-at-age: a climate change connection?

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Background

Herring in BC usually spawn during March and April. Spawning is earlier in California and later in Alaska. Eggs incubate for 2-3 weeks before hatching into pelagic larvae. The larval stage lasts for several months before larvae metamorphose into juveniles that stay mainly in shallow, nearshore waters. When they reach about one year of age, herring juveniles gradually move to deeper waters and most mature sexually during their third winter of life (age 30-36 months). At this time they are 'recruited' and join older herring and move to shallow inshore areas to spawn. The relative biomass of the recruiting cohort can be large, sometimes exceeding fifty percent by number, of the total adult population. At the southern edge of their range (California), herring have a smaller size-at-age and relatively higher relative fecundity (more eggs per fish weight) than fish in BC or Alaska. In general, the size-at-age three, when most BC herring recruit, is less variable than the size-at-age of older, post-recruit herring. Ocean climate, especially ambient ocean temperature, may affect spawning time and distribution. The work described below takes this a step further by presenting evidence that size-at-age may decreases and relative gonad sizes increases during recent ocean conditions.

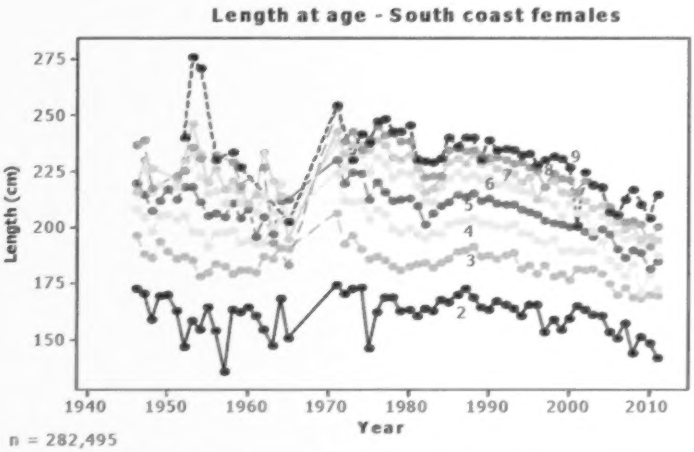

Figure 1. Example of the decrease in length-at age for female herring from the south coast of BC (Straight of Georgia, West Coast of Vancouver Island and the Central Coast of BC combined). Numbers in plot are herring ages in years.

Observations

Length-at-age and weight-at-age of post-recruit herring has decreased in all BC herring populations since the 1970s (Therriault et al. 2009; Fig. 1). In years prior to 1970, size-at-age varied, with relatively large size-at-age in the 1950s and earlier.

The decrease in size-at-age of herring since the 1970s, when the size-selective herring roe fishery started, has led some commentators to suggest the fishery is responsible for the decrease in size-at-age; however the impact of size-selective fisheries is not well-established (Hilborn and Minte-Vera, 2008). Further, size-at-age has decreased in some BC and Alaskan herring populations that have not been fished since the roe fishery started in the early 1970s. In addition to declining size at age for herring in BC, size-at-age has declined in California (Fig. 2) and some but not all of SE Alaska (Fig. 3). We cannot rule out size-selective impacts of fishing on Pacific herring as a factor affecting size-at-age but the consistent pattern of change in size-at-age among different populations from a broad latitudinal range indicates other factors may be important.

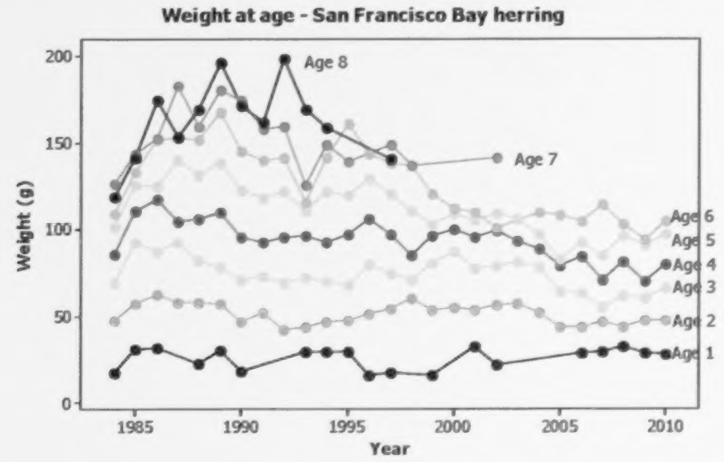

Figure 2. Changes in weight-at-age of herring from San Francisco Bay (data from California Department of Fish and Game)

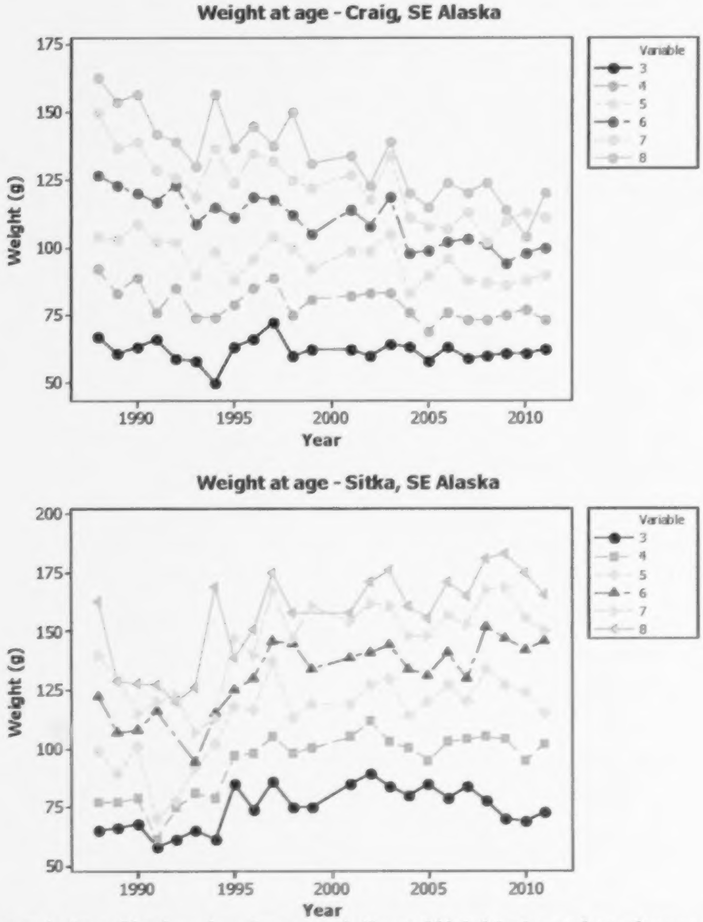

Figure 3. Weight at age in two Alaskan herring populations. Weight at age has decreased in herring from Craig, Alaska (top) but increased in Sitka Alaska (bottom). The 'variables' in the box indicate age in years.

Climate change can explain changes in fish growth and decreasing size-at-age. Ocean temperatures are increasing in many parts of the northeast Pacific (for example see Chandler 2012, elsewhere in this research document) as well as hypoxia (Whitney et al. 2007, Roegner et al. 2011, Pierce et al. 2012). Hypoxia has been shown to result in decreased growth (e.g. Stierhoff et al. 2006) and recent evidence indicates that this maybe impacting fish in parts of the northeast Pacific (Deutsch et al. 2011). Increasing temperature has been shown to cause decreases in fish growth implicated in a number of studies (e.g. Neuheimer et al. 2011).

If size-at-age is related to climate change, then the impact varies in SE Alaska. Weight-at-age of two herring stocks has decreased in the most southern regions of SE Alaska, where ocean temperature has increased: Craig (Fig. 3 top) and West Behm Canal (WBC). There has been no fishery in WBC for decades. In contrast, weight-at-age does not appear to be decreasing in northern (SE Alaska) stocks, including Sitka (Fig. 3 bottom) where mean sea temperature is lower.

Although size-at-age has decreased there is no evidence that herring are in 'poorer condition' as reflected in changes in the length-weight relationship or computation of various 'condition factors'. There is evidence, however, of a relative increase in the gonad sizes – or 'gonosomatic' index (gonad weight/total weight). The relationship between herring weight and gonad weight is non-allometric: in general larger herring have proportionately larger gonads than smaller herring (Fig. 4). Therefore the temporal change in gonad size is best seen when compared among fish of identical size. When examined by specific length intervals, both females and males show a temporal increase in their relative gonad weight and a corresponding decrease in their somatic weight.

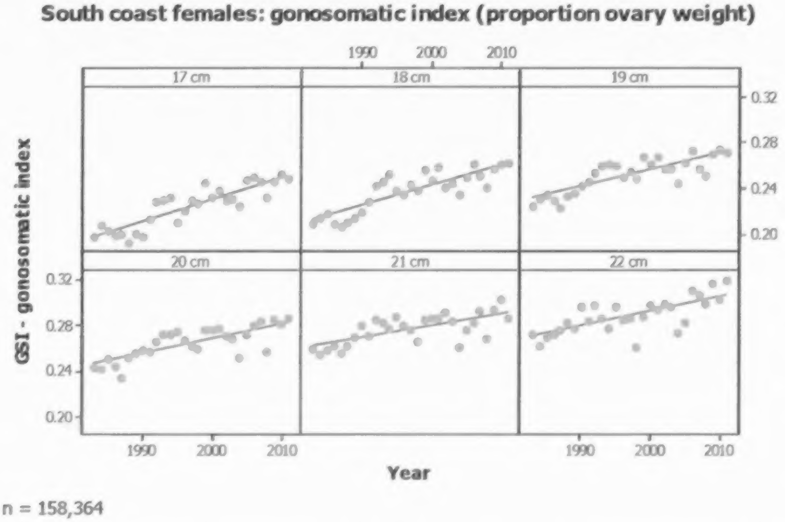

Figure 4. The relative size of the weight of herring ovaries, known as the gonosomatic index (GSI) has increased relative to total weight. Each point is the mean GSI for each cm-length group. The straight line is a fitted regression which is significant (p<0.01) for all panels.

Implications

Herring may be responding to climate change in a way that is consistent with the way that they exhibit geographic variation. For instance, in terms of growth, BC herring now more closely resemble California herring (of several decades ago) because they are slower-growing and have increased their gonad sizes. It appears, however, that California herring have also undergone similar temporal decreases in size-at-age and there also is indirect evidence of an increase in roe production in recent fisheries in San Francisco Bay. A potential implication for future fisheries is that if California herring can be used as a model, BC herring may be able to persist, and perhaps even thrive, with modest increases in ocean temperature.

A specific implication for herring research and management is that the estimate of relative fecundity used for annual assessments (as a coefficient for converting observed eggs numbers from herring spawn into estimates of herring spawning biomass), usually assumed to be about 100 eggs/g of fish wet weight (of spawning stock biomass of both sexes), may require new data input and adjustment.

If the reduction in herring size-at-age is related to changes in ocean climate, then there are at least two potential mechanisms that may not be mutually exclusive: an increase in ocean temperature and/or an increase in hypoxia (or decrease in dissolved oxygen). Either condition could lead to the observed changes in size-at-age in herring.

These topics are under active investigation at the Pacific Biological Station and collaborators in other laboratories.

Acknowledgments

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2.2.7 Sardine

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Description of indices

An annual surface trawl survey conducted off the west coast of Vancouver Island (WCVI), the U.S. sardine stock assessment, and Canadian commercial catches of sardine provide indices of sardine population trends. Annual WCVI catch per unit effort (CPUE) and commercial catch estimates are utilized to estimate the regional biomass of sardines in Canadian waters. The WCVI survey began in 1997, and switched to night-time sampling in 2006. Results from the WCVI survey and the U.S. assessment of the population are used to estimate sardine migration rates into Canadian waters (Figs. 1-3). This information is then used to forecast subsequent seasonal abundance and provide science advice on recommended catch levels (e.g. DFO 2011).

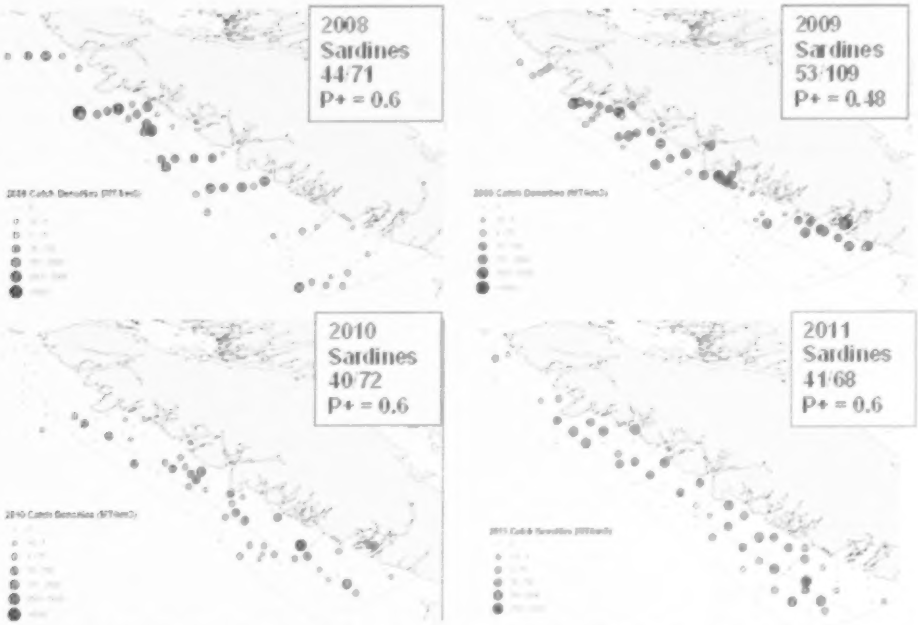

Figure 1. West coast of Vancouver Island (WCVI) summer trawl survey sampling locations and relative sardine catch densities for 2008-2011 (tonnes per km^3 trawled). P+ = the fraction of tows where sardine were caught.

Status and trends

Pacific sardine is a migratory species, annually migrating between spawning grounds in southern California where they spawn during winter and spring months to the rich feeding areas off WCVI where they mainly forage during summer and fall months; the older and larger fish tend to move even further north (Clark and Janssen 1945, Flostrand et al. 2011). The sardine fishery in Canadian waters collapsed in 1947 and by the early 1950s off California. Sardine returned to southern Vancouver Island waters in 1992 after a 45 year absence, and expanded their seasonal distribution northward throughout the west coast of Vancouver Island, Hecate Strait and Dixon Entrance by 1998 (McFarlane et al. 2001). In 2011, WCVI survey catch densities of sardine increased from 2010 but were not as high as those observed in 2006 and 2008-2009. (Figs. 1 and 2).

The most recent U.S. sardine assessment suggests that the California Current (Northeast Pacific) sardine population abundance off Canada and the U.S. increased rapidly through the 1980s and 1990s, peaking at over 1,400,000 tonnes in 2000, and approximately 1,250,000 tonnes in 2006 (Hill et al. 2011). The population assessment shows declines from 2006 to 2009 but some increase from 2009 to 2011 (Fig. 3). The most current population biomass estimate for age 1 year and older sardine is approximately 988, 400 tonnes (July 1- December 31, 2011).

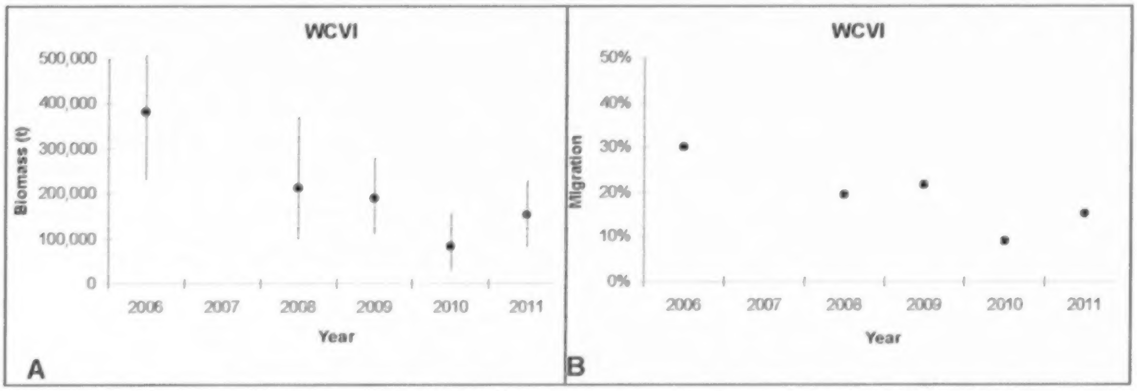

Figure 2. West coast of Vancouver Island (WCVI) summer trawl survey 2006, 2008-2011 (A) biomass estimates and 95% confidence intervals, and (B) migration rate estimates (related to Semester 1 age 1 year and older population biomass from Hill et al. 2011).

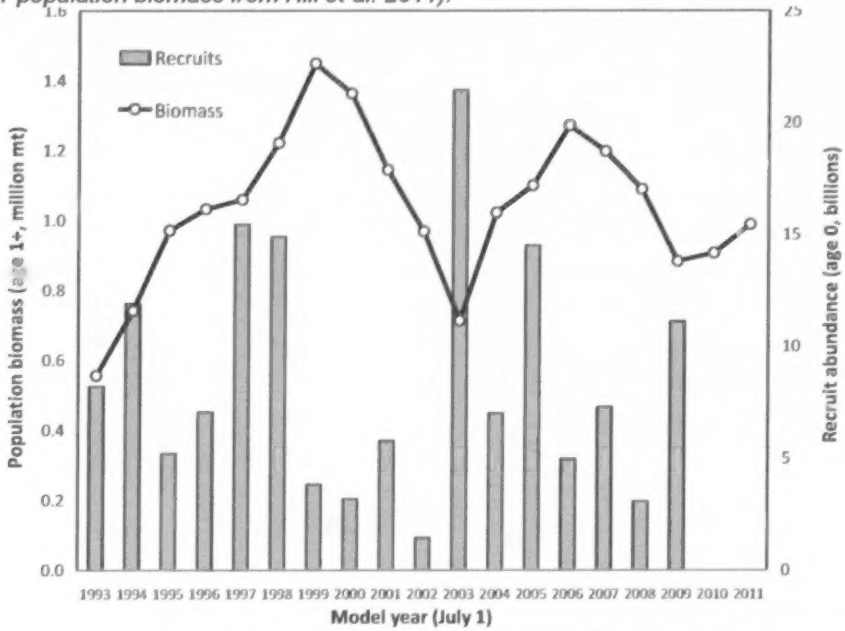

Figure 3. Abundance trends for spawning stock (age 1 year and older) biomass (line plot, millions of tonnes) and year class strength (bar plot, billions of age-0 fish). Information from Hill et al. 2011, model "X5").

In B.C, commercial purse seine fishing for sardine has been conducted in sheltered waters (especially inlets) along the southern central coast, within Queen Charlotte Strait and Queen Charlotte Sound, and the WCVI, represented by several Pacific Fishery Management Areas (PFMAs, Table 1, Fig. 4). Relatively small proportions of the annual total allowable catches were realized during initial years following the re-opening of the commercial fishery in 2002, due, in part, to modest sardine markets at the time and competing fisheries for vessel and plant resources. Most B.C. waters have been open to commercial sardine fishing except where there are permanent fishing closures or bycatch concerns. In 2011, the total sardine catch from B.C. waters was 20,621 tonnes, approximately 95% of the total allowable catch of 21,917 tonnes. All harvesting occurred off the WCVI, with the majority of catch coming from Pacific Fishery Management Areas 23, 25 and 123.

Table 1. Annual sardine total allowable catch (TAC) and realized seine catch in British Columbia (B.C.) by Pacific Fishery Management Area (PFMA) for 2006-2011 (in tonnes).

Region	**Year:**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
B.C.	TAC:	13,500	19,800	12,491	18,196	23,166	21,917
	PFMA		**Realized catch by year and PFMA**				
Mainland	7	0	26	0	0	0	0
	8	0	0	358	564	18	0
	9	0	25	522	3,370	1,925	0
	10	0	0	1,421	3,196	1,049	0
	12	1,558	1,181	2,462	131	320	0
	Subtotal	*1,558*	*1,232*	*4,764*	*7,262*	*3,312*	*0*
WCVI	20	0	168	0	0	0	0
	23	0	105	820	3,655	5,178	5,145
	24	0	0	301	57	1,149	677
	25	0	1	2,025	3,188	6,008	5,787
	26	0	0	1,179	249	133	1,593
	27	0	0	0	0	3,486	1,694
	121	0	0	0	0	0	77
	123	0	0	1,346	916	3,185	4,683
	124	0	0	0	0	46	703
	125	0	0	0		42	199
	126	0	0	0	0	0	62
	Subtotal	*0*	*274*	*5,671*	*8,065*	*19,227*	*20,621*
B.C.	**All**	**1,558**	**1,507**	**10,435**	**15,327**	**22,538**	**20,621**

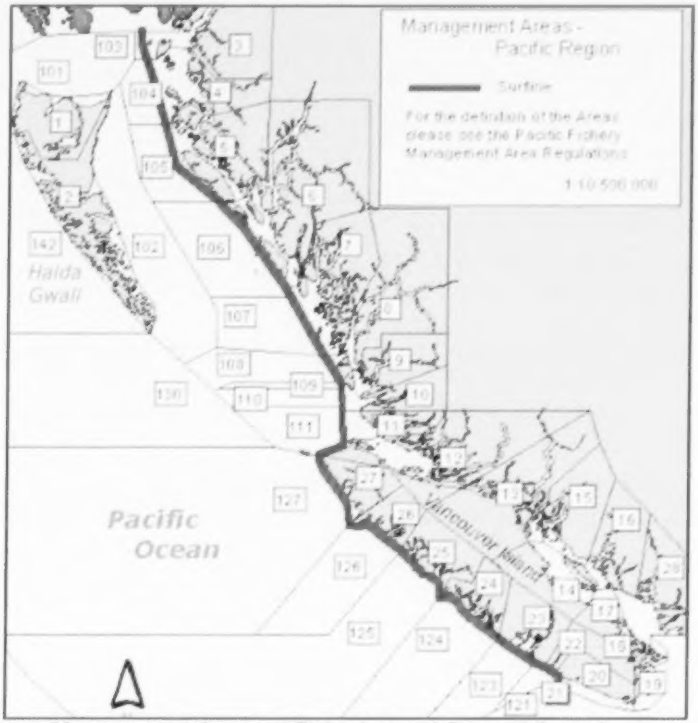
Management Areas -
Pacific Region
Surfline
For the definition of the Areas please see the Pacific Fishery Management Area Regulations
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Figure 4. Pacific Fishery Management Areas of Fisheries and Oceans Canada.

Factors causing trends in abundance and distribution

Historical sardine abundance has been extremely variable along the US and Canadian west coast, cycling over approximately 60-year periods (Cushing 1971, Hill et al. 2011). The number of sardines and the timing of their annual northward migration are influenced, in part, by environmental factors and stock size and recruitment relationships that are not well understood (Lo et al. 2010, Hill et al. 2011). The decline in sardine biomass in the late 1940s was attributed to environmental conditions and overfishing (Clark and Marr 1955, Jacobson and MacCall 1995). During cold years, such as in the 1950s to 1970s, sardine productivity was low and the distribution was contracted into the southern part of their range (Hill et al. 2011, Jacobson and MacCall 1995). Recent warm years, associated with increased sardine productivity (Jacobson and MacCall 1995) and larger stock size have resulted in a more northerly seasonal distribution of the stock (McFarlane et al. 2001, Hill et al. 2011, Zwolinski et al. 2011, Zwolinski et al. 2012).

Implications of those trends

Commercial fisheries for Pacific sardine in British Columbia (BC) began in early 1995 and were primarily experimental with only a small proportion of the total allowable catch (TAC) being harvested. More recently (2008-2011) commercial catch has increased in importance in BC (10,435-22,538 tonnes) and, with increases in population and seasonal abundance estimates in 2011, the TAC for the 2012 fishing season is expected to be the highest since the fishery re-opened after the population collapsed in the 1950s.

Pacific sardine are consumed by a variety of fish, such as coho and Chinook salmon (Chapman 1936) and spiny dogfish, as well as by marine mammals, such as humpback whales, California sea lions and other pinnipeds. Historically, sardine populations have undergone extreme variations in abundance and it is likely that predators have adapted to utilize this resource when it is abundant. Diet data time series from sardine predator foraging observations would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

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2.2.8 Eulachon

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Description of indices

Three indices of eulachon (*Thaleichthys pacificus)* population trends are: 1) eulachon catches occurring in annual offshore shrimp trawl surveys off the West Coast of Vancouver Island (WCVI) and in Queen Charlotte Sound (QCS), 1973- 2010, 2) commercial eulachon catches in the Fraser and Columbia River systems, and 3) a spawning stock biomass estimate based on annual Fraser River eulachon egg and larval surveys. Information from these indices provides information on population trends and science advice regarding eulachon catch recommendations.

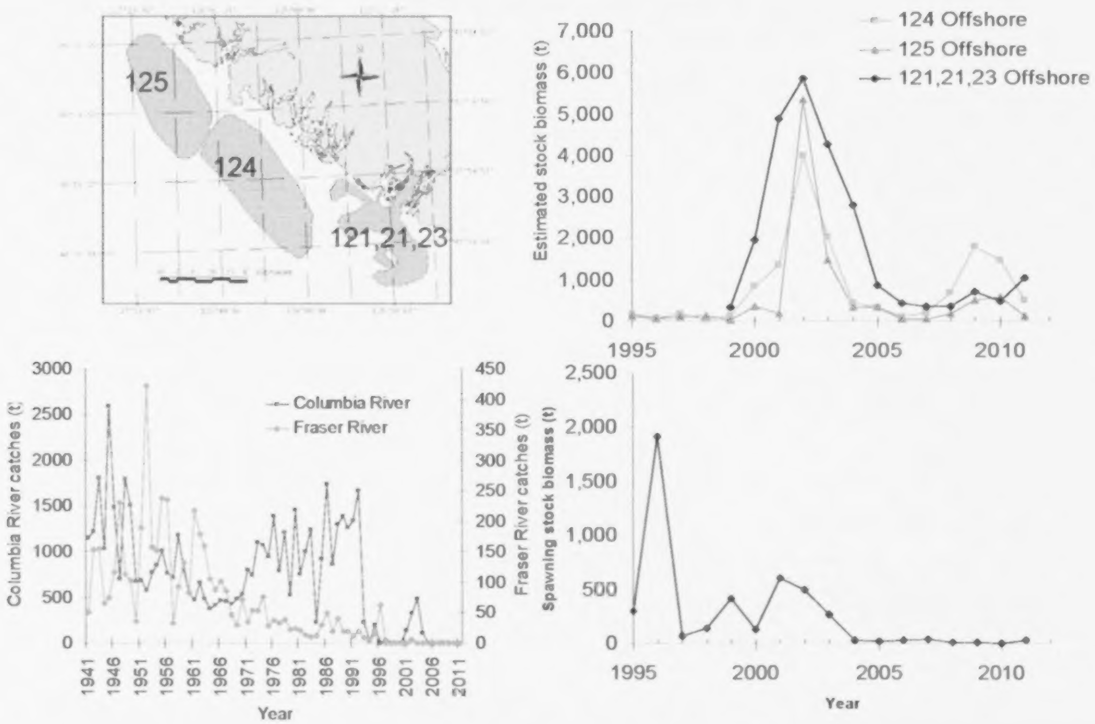

Figure 1. Three potential indices of eulachon abundance. The upper, right panel shows recent trends in the offshore shrimp survey trawl catches of eulachon in areas shown in the upper, left panel. The lower, left panel shows the commercial catches of eulachon in the Columbia and Fraser River systems. The lower, right panel shows the estimated spawning stock biomass of eulachon from egg and larval surveys in the Fraser River system.

Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. Indices of eulachon abundance in central and southern British Columbia rivers remain at low levels, whereas offshore shrimp trawl survey catches indicate juvenile eulachon abundance peaked in 2002 and again, although at a much lower abundance, in 2009

(Fig. 1, top right). Offshore indices of juvenile eulachon abundance, however, do not necessarily reflect the abundance of adult eulachon that return to rivers. The estimated eulachon spawning stock biomass in the Fraser River decreased in 1994 and has consistently been below the 150 tonne response point since 2004 (Fig. 1, bottom right; Hay et al. 2003). The biomass in the Fraser River will be estimated by an egg and larval survey in April-May, 2012. Catches in the Columbia River system decreased dramatically in the early-1990s (Fig. 1, bottom left). Columbia River eulachon were federally-listed in the U.S.A. as threatened under the Endangered Species Act (ESA) effective May 17, 2010 and all eulachon-directed fisheries were closed in 2011 (http://www.nmfs.noaa.gov/pr/pdfs/fr/fr75-13012.pdf). COSEWIC has recently assessed eulachon in BC as three populations: the Central Pacific coast population and Fraser River populations were assessed as endangered, and the Nass/Skeena Rivers population is currently being reassessed (2011 report: COSEWIC 2011). A recovery potential assessment is in progress.

Factors causing those trends

It is unknown what is causing declining trends in eulachon abundance. In-river factors may include habitat loss, pollution, directed fisheries, logging, and marine mammal predation. Marine factors that may affect eulachon abundance include: oceanographic conditions, bycatch in commercial fisheries, and trophodynamic changes, such as food availability and predator abundance.

Implications of those trends

Reduced biomass of eulachon has negative implications for First Nations and commercial fishers. Eulachon are socially and culturally significant to local First Nations and are fished by First Nations, recreational and commercial fishers.

Reduced eulachon abundance also likely has negative impacts on their predators. Important predators of eulachon include: marine mammals particularly sea lions in the estuaries, and porpoises, Chinook and coho salmon, spiny dogfish, Pacific hake, sturgeon, Pacific halibut, walleye pollock, sablefish, rockfish, arrowtooth flounder, and others (Levesque and Therriault 2011). Diet data time series of all animals in the ecosystem would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

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2.2.9 Albacore tuna in BC waters: 2011 was a poor year

John Holmes, Fisheries & Oceans Canada

Albacore tuna (*Thunnus alalunga*) is a highly migratory pelagic species widely distributed in tropical and temperate waters of all oceans. There are two distinct stocks of albacore in the Pacific Ocean, one in the South Pacific and one in the North Pacific. Juvenile albacore from two to four years of age in the North Pacific stock are the primary target of the Canadian troll fleet along the west coast of North America and the adjacent high seas waters.

Juvenile albacore are attracted to areas of sharp temperature and salinity gradients (fronts) in the transition zone between the subarctic and subtropical gyres in the North Pacific (Laurs and Lynn 1977). Based on fishery data, water temperatures between 14 and 19°C within the transition area are important for albacore, and albacore in coastal areas are found primarily seaward of the continental shelf edge. On average, transition zone waters between 14 and 19°C are observed within the Canadian exclusive economic zone (200 mile limit) beginning in mid to late July and persist through October. A poor year for the albacore tuna fishery is characterized by late arrival of the frontal zone and early departure, leading to a reduced overlap in time and space between these waters and the continental shelf edge where upwelling dominates productivity.

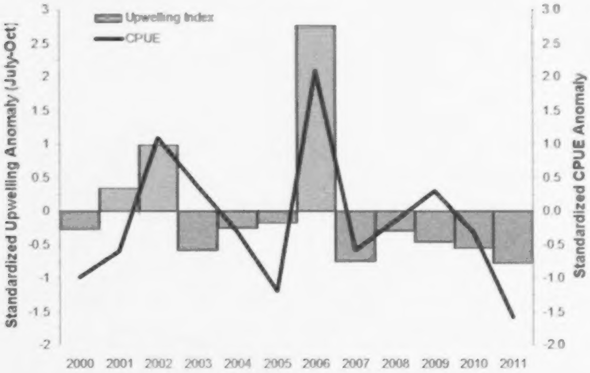

Figure 1. Standardized anomalies of catch rate (fish/day) in Canadian waters (black line) and July-October upwelling index values at 48°N, 125°W (bars). Zero (0) on both scales is the average for 2000-2009. Standardized anomalies (A) are calculated as:

$$A_{2011} = \frac{(X_{2011} - \overline{X}_{2000-2009})}{s_{2000-2009}},$$

where X is the observed value, $\overline{X}$ is the average for 2000-2009, and s is the standard deviation.

Stock assessment scientists often use catch-per-unit-effort (CPUE) or catch-rate (total catch divided by the effort to achieve that catch) to index fish abundance. Annual CPUE for albacore in BC coastal waters averaged 66 fish/day during the 2000-2009 period, and in 2011 was well below average at 34 fish/ day (Fig. 1). The 2011 CPUE is the lowest value since 2000; the highest was in 2006 at 109 fish/day. The 2000-2009 period is used as the base period for these comparisons because logbook reporting of catch and effort, from which these data are derived, exceeded 80% in 2000 for the first time and since 2003 has been > 95% of known catch. Catch rates are positively correlated (r = 0.78) with July-Oct upwelling index anomalies at 48°N, 125°W (www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html), where positive anomalies indicate higher than average upwelling during the summer and fall and negative anomalies are lower than average upwelling for the same period. One potential mechanistic explanation for this correlation is that above average upwelling supports higher productivity in lower trophic levels on the continental shelf, which in turn enhances albacore foraging opportunities on small pelagic fish species (anchovy, sardine, mackerel, hake) and squids (Glaser 2009) at the edge of the continental shelf. Stronger upwelling winds blow from the northwest along the Vancouver Island shelf, and not only upwell more nutrient-rich water near shore, but also push this water and its richer marine life toward the outer edge of the continental shelf, where tuna prefer to feed. This stronger offshore flow of surface waters might also intensify the frontal features offshore of the shelf break, concentrating prey for tuna.

August is the first consistently productive month for albacore in Canadian waters because transition zone waters have moved sufficiently far north. By August 2011, transition zone waters were as far north as Haida Gwaii along the continental shelf and the highest CPUEs occurred in sporadic locations along the continental shelf and more consistently in offshore waters (Fig. 2). The majority of coastal areas in both Canada and the United States accessed by the Canadian fishery in August 2011 had catch rates well below the 2000-2009 average for these areas, consistent with below-average upwelling (Fig. 1). Above-average catches tended to be offshore, outside the EEZs of Canada and the United States, and along the shelf break north of Vancouver Island. Total catch of albacore in Canadian waters was 675 t, which was 12.5% of the total catch, and a 71% decrease relative to the catch in the Canadian waters in 2010. Historically, about 80% of the Canadian albacore catch has occurred in coastal waters off of Washington and Oregon (through access provisions in the Canada-US Albacore Tuna Treaty), approximately 14% in Canadian waters, and the remainder in adjacent high seas waters.

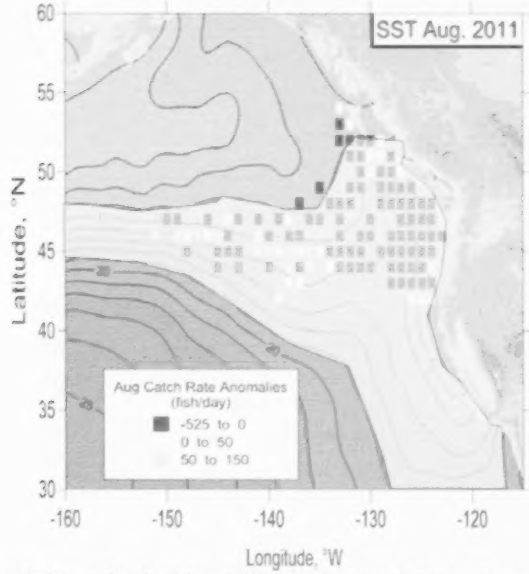

Figure 2. CPUEnomalies (fish/day) based on logbook data in areas fished by the Canadian fleet in Aug 2011, overlaid on monthly Aug SST isotherms. The transition zone, defined as SST between 14 and 19°C, is outlined in the light cross hatching. Anomalies are calculated for 1° x 1° spatial blocks. Blocks in blue are poor catch rates (below-average); yellow blocks are moderately above-average catch rates, and green blocks are good above-average catch rates.

The late arrival of transition zone waters in August and below-average upwelling winds along the continental shelf-break at 48°N (Fig. 1) resulted in fewer albacore migrating into Canadian waters in 2011 (Figs. 1 and 2), i.e., 2011 was a poor year for albacore fishing. Assessments of interannual temporal and spatial variation in albacore distribution and abundance may benefit from considering indices of environmental processes at various spatial scales.

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3.210 Average ocean conditions for salmon on the west coast of Vancouver Island in 2011

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In order to inform managers of the likely short-term impacts of ocean and climate conditions on Pacific salmon survival and returns, NOAA Fisheries has developed a simple report card system with a series of indicators that are monitored as part of their ongoing integrated ecosystems surveys off the Oregon and Washington coasts (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm#Table1). The indicators are ranked from best to worst, with the best value getting the rank of one, and the worst getting the highest rank (Peterson 2012, elsewhere in this research document). For ease of visualization, the best conditions for salmon are colour-coded green, the worst are colour-coded red, and the intermediate values are colour-coded yellow (hence the alternative name of "stoplight" for this rating system). Finally, the ranks of the indicators are also averaged in a given year to provide an overall assessment of the ocean and climate conditions that prevailed that year.

We applied this approach to a series of climate indices and ongoing monitoring activities off the west coast of Vancouver Island to illustrate the potential utility of this approach for British Columbia salmon (Table 1). Overall, this stoplight table indicates that ocean conditions were not favourable to salmon in 1998 and from about 2003 to 2006 off the west coast of Vancouver Island (especially 2005), but better for salmon in 1999-2001 and then again in 2008. Similar results have been reported by NOAA for the Oregon and Washington coasts (Peterson 2012, elsewhere in this research document). This is not surprising given that both programs conduct their monitoring activities in the Northern California Current System. For 2010 and 2011, the conditions were overall average with some mixed signals (some greens and reds for both years).

Table 1. Ocean ecosystem indicators for the west coast of Vancouver Island. Indicators are ranked from one (best for salmon) to fourteen (worst for salmon), and colour-coded green and red for best and worst conditions for salmon respectively, and yellow for neutral conditions.

Environmental Variables	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***
PDO (May-Sep)	8	3	5	4	9	13	12	14	10	11	1	7	6	2
NPGO (May-Sep)	12	4	3	2	8	9	11	14	13	7	1	10	5	6
ENSO (May-Sep)	11	2	6	7	13	8	10	9	12	3	5	14	1	4
Mean SST - WCVI (Amphitrite) - Mar-Jun	13	1	6	2	3	10	12	14	9	4	5	7	11	8
C/N Zooplankton Ratio (WCVI)	13	6	12	7	5	8	3	14	10	9	1	11	4	2
Northern (Boreal) Copepods	14	3	6	7	4	9	11	13	12	5	1	2	8	10
Southern Copepods	14	7	8	5	4	13	10	12	11	3	2	1	9	6
Sockeye prey (3 to 5 mm T. spinifera)	9	2	1	6	7	12	3	14	11	5	4	8	10	13
Coho prey (T. spinifera > 19 mm)	10	12	4	5	3	11	7	13	6	9	13	2	8	1
Neocal Timing														
WCVI Coho Summer Growth	13	1	3	7	2	8	4	14	9	10	6	11	5	12
Mean Rank	11.7	4.1	5.4	5.2	5.8	10.1	8.3	13.1	10.3	6.6	3.9	7.3	6.7	6.4
Rank of Mean Ranks	13	2	4	3	5	11	10	14	12	7	1	9	8	6

We also produced a similar stoplight table for the marine survival of Robertson Creek coho and Chinook salmon, and Barkley Sound sockeye salmon (Table 2). For the most part, the marine survival seems to track the ocean and climate indicators reasonably well, as there was a strong correlation between the mean ranks of salmon survival and mean ranks of the indicators

(Fig. 1). Hence, given that ocean conditions were overall average for 2010-2011, we expect that smolts entering the ocean in those years had average survival rates.

Table 2. Ranks for the marine survival of Barkley Sound sockeye salmon, Robertson Creek coho and Chinook salmon by ocean entry years. Colours represent high (green), intermediate (yellow), and red (low) marine survivals.

Salmon survival	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Barkley Sound sockeye	11	5	3	7	5	9	9	11	8	4	1	2
Robertson Creek Coho	9	4	2	8	3	10	6	12	7	5	1	11
Robertson Creek Chinook	12	6	2	5	1	8	3	11	7	10	4	9
Mean Rank	10.667	5	2.3333	6.6667	3	9	6	11.3333	7.3333	6.3333	2	7.3333
Rank of Mean Ranks	11	4	2	7	3	10	5	12	8	6	1	8

A close examination of the residuals of this relationship revealed that, except for the 1998 ocean entry year, the mean ranks of survival were higher in odd years compared to even years (Figs. 1 and 2). This pattern is currently difficult to explain, at least in terms of competition. It is generally assumed that this odd-even year pattern reflects competition with pink salmon as they often exhibit odd-even year patterns of abundance in some areas of the North Pacific Ocean (Ruggerone and Nielsen 2004). For instance, juvenile pink salmon are virtually absent in odd years in the Strait of Georgia but very abundant in even years, and have been showed to compete with juvenile coho salmon (Beamish et al. 2008). However, there are very few juvenile pink salmon off the west of Vancouver Island during summer and fall in either odd or even years, and there is no strong odd-even year pattern of juvenile pink salmon abundance in coastal waters north of Vancouver Island (S. Tucker, unpublished data). The three species of salmon also exhibit widely divergent migration behaviour with fast migrants, slow migrants and coastal residents (Morris et al. 2007; Trudel et al. 2009; Tucker et al. 2009, 2011, 2012). In particular, west coast of Vancouver Island Chinook salmon remain within a few hundred kilometres of their natal streams during their first year at sea (Trudel et al. 2009; Tucker et al. 2011, 2012), indicating that they do not encounter many pink salmon, at least during this initial time period. Hence, competition between west coast of Vancouver Island salmon and pink salmon is unlikely to occur in coastal waters during their first year at sea, but may still occur later in the Gulf of Alaska as sub-adults.

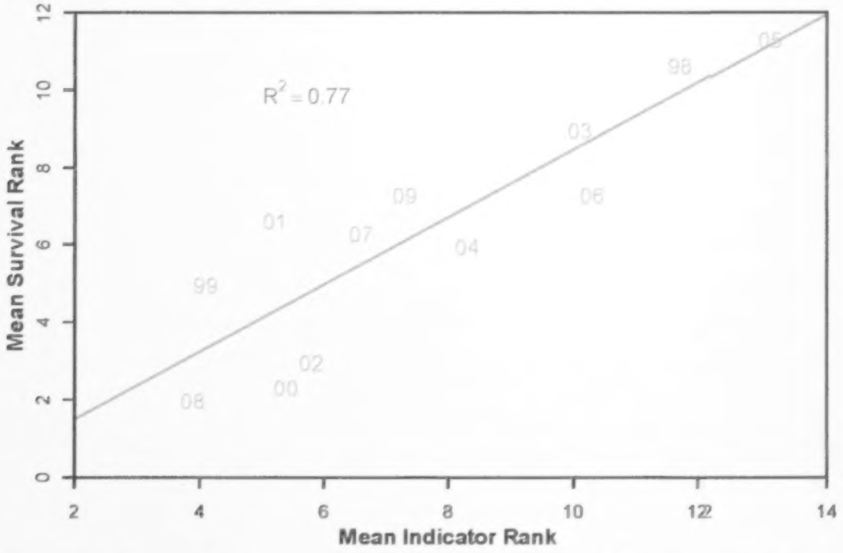

Figure 1. Relationship between the mean rank for the marine survival of west coast of Vancouver salmon and the mean rank of the ecosystem indicators for that region by ocean entry year.

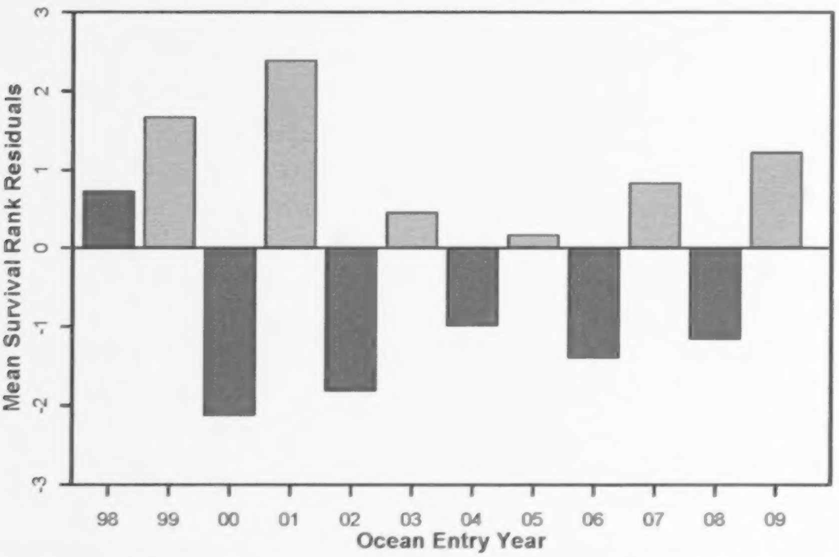

Figure 2. Residuals of the relationship between the mean rank for the marine survival of west coast of Vancouver salmon and the mean rank of the ecosystem indicators for that region by ocean entry year. Red bars: odd years; blue bars: even years.

Although the stoplight table provides a quick overview of the conditions experienced by salmon, different stocks performed differently, and their marine survival was best correlated to a few variables in the table. Notably, Barkley Sound sockeye were best correlated to the northern and southern copepod anomalies (Spearman rank correlation; r=0.88-0.93), whereas Robertson Creek coho and Chinook salmon were strongly correlated to the growth of juvenile coho salmon off the west coast of Vancouver Island (Spearman rank correlation; r=0.76-0.87). Based on these indicators, the outlook for Robertson Creek coho salmon returns in 2011 and 2012 (or Robertson Creek Chinook in 2012 and 2013) are average and poor, respectively. Indicators are average for Barkley Sound sockeye returns in 2012 and 2013.

Notes:

1. PDO data from http://jisao.washington.edu/pdo/PDO.latest
2. ENSO data from http://www.esrl.noaa.gov/psd/enso/mei/table.html
3. NPGO data from http://www.o3d.org/npgo/data/NPGO.txt
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3.2.11 Population trends in seabirds, intertidal bivalves and eelgrass fish communities in Pacific Rim National Park Reserve

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Resource Conservation, Pacific Rim National Park Reserve of Canada

We review the annually averaged May-to-August marine abundance trends of the more common seabirds in Barkley Sound and an adjacent coastal stretch conducted by staff of Pacific Rim National Park Reserve in 1995 - 1996 and 1999 - 2011 along three transects – two in the Broken Group Islands and one further south along the West Coast Trail (BGI-Inner, BGI-Outer, and WCT, Fig. 1). We also present trends for intertidal bivalves monitored since 1997 at five locations in the Broken Group Islands and trends in species richness and abundance in eelgrass fish communities sampled at 24 eelgrass meadows in Barkley and Clayoquot Sounds since 2001. The data (annual abundance estimates) were analysed for overall slope (trend) as well as any break points across the entire time series using generalised estimating equations implemented in TRIM (http://www.ebcc.info/trim.html) or generalized linear mixed models (GLMM) implemented within the Ime4 package in R (http://www.r-project.org). Bird abundance was expressed as average total count per transect. Bivalve abundance - as total number of animals per site estimated via two-stage sampling (e.g. Norgard et al. 2010). Fish abundance - as total individuals (or species) of combined three sets of seines per site per year (see Robinson et al. 2011 for details).

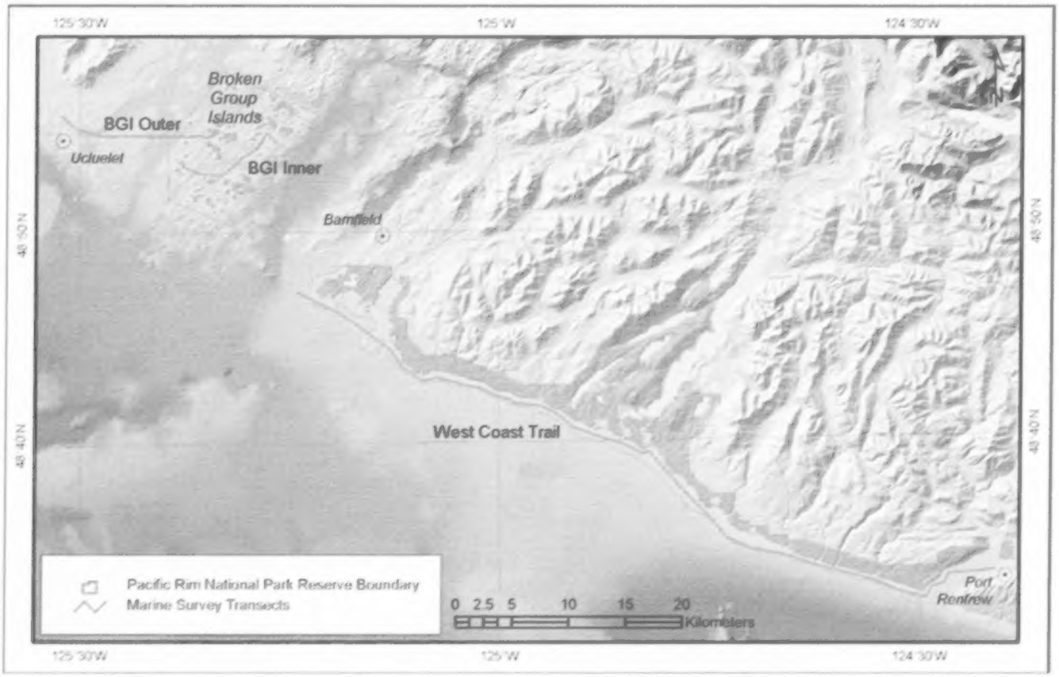
125°30'W
125°W
124°30'W
48°50'N
48°40'N
Broken Group Islands
BGI Outer
Ucluelet
BGI Inner
Bamfield
West Coast Trail
Port Renfrew
Pacific Rim National Park Reserve Boundary
Marine Survey Transects
0 2.5 5 10 15 20 Kilometers

Figure 1. At-sea seabird transects in the waters of Pacific Rim National Park Reserve of Canada. The Broken Group Islands unit of the Park is in the top left corner.

Seabirds

The results are presented for nine taxa that comprise >95% of all individuals counted: common murre (*Uria aalge*), marbled murrelet (*Brachyramphus marmoratus*), Pacific loon (*Gavia pacifica*), pelagic cormorant (*Phalacrocorax pelagicus*), pigeon guillemot (*Cepphus columba*), red-necked phalarope (*Phalaropus lobatus*), rhinoceros auklet (*Cerorhinca monocerata*), sooty shearwater (*Puffinus griseus*) and three species of scoters (black *Melanitta nigra*, surf *M. perspicillata* and white-winged *M. fusca*) combined. Year 2011 was very similar to 2010 in that most species displayed among the highest abundances in the time series, scoters being the only exception. The higher-than-average abundances in 2011 lowered the overall rates of decline in the declining species (murres, murrelets, auklets) and increased the rates of increase in the increasing or stable species (cormorants, guillemots) relative to 2010.

Table 1. Summary of overall seabird population trends and recent population trends as determined by the most recent break point in the slope. All slopes (se = standard error) are reported. Significant ($p<0.05$) slopes are coded in red for decreasing populations and green for increasing populations.

SPECIES	Overall trend 1995-2011, slope (se)	Recent trend (years)	2011 Abundance Comment
Common murre	-0.087 (0.013)	Uncertain 2006-10	Highest since 2004
Marbled murrelet	-0.031 (0.008)	Increasing 2006-11	Both 2010 and 2011 highest since mid 1990s
Pacific loon	**-0.022 (0.016)**	Uncertain, high year-to-year variability	About average
Pelagic cormorant	0.020 (0.009)	Uncertain, high year-to-year variability	Higher than average
Pigeon guillemot	0.060 (0.009)	Increasing 2006-2011	Highest since 1995
Red-necked-phalarope	0.148 (0.031)	Uncertain, high year-to-year variability	Higher than average
Rhinoceros auklet	-0.037 (0.012)	Increasing since 2009	Both 2010 and 2011 highest on record
Sooty shearwater	**0.001 (0.139)**	Increasing 2007-11	Highest since 1999
Scoters	-0.093 (0.005)	Increased 2006-10	(from 1994, WCT only), below average

Most species continue to respond positively to the cool local oceanic conditions observed in 2007 - 2011 and are on the rebound. Cooler coastal waters in BC are generally thought to result in increased energy flows through phyto- and zooplankton to juvenile fish to seabirds (Mackas et al. 2007; Mackas et al. 2012, elsewhere in this research document). The steep increases in abundance in the past few years, including 2011, suggest that birds congregate in areas with abundant food sources. Pacific herring (*Clupea pallasi*) has displayed a positive trend off WCVI over the past three-four years although still below the commercial harvest threshold (DFO 2011; Boldt et al. 2012, elsewhere in this research document). Seabird abundance in this study co-varies with herring abundance (Fig. 2) likely due to both herring being the direct prey for different seabird species and/or generally reflecting high productivity trends in coastal waters. For example, pre-spawn herring biomass explained 48% and 49% of inter-annual variability in common murre and marbled murrelet numbers. It is not clear why the abundance of scoters was low in 2011 and it could be for a numbers of reasons unrelated to local conditions (e.g. fewer birds remaining to over-summer or delayed onset of fall migration).

The seabird trends reported here generally correspond with 10-year trends presented in the recent British Columbia Coastal Waterbird Survey newsletter by Birds Canada (http://www.bsc-eoc.org/library/bccwsnews.pdf).

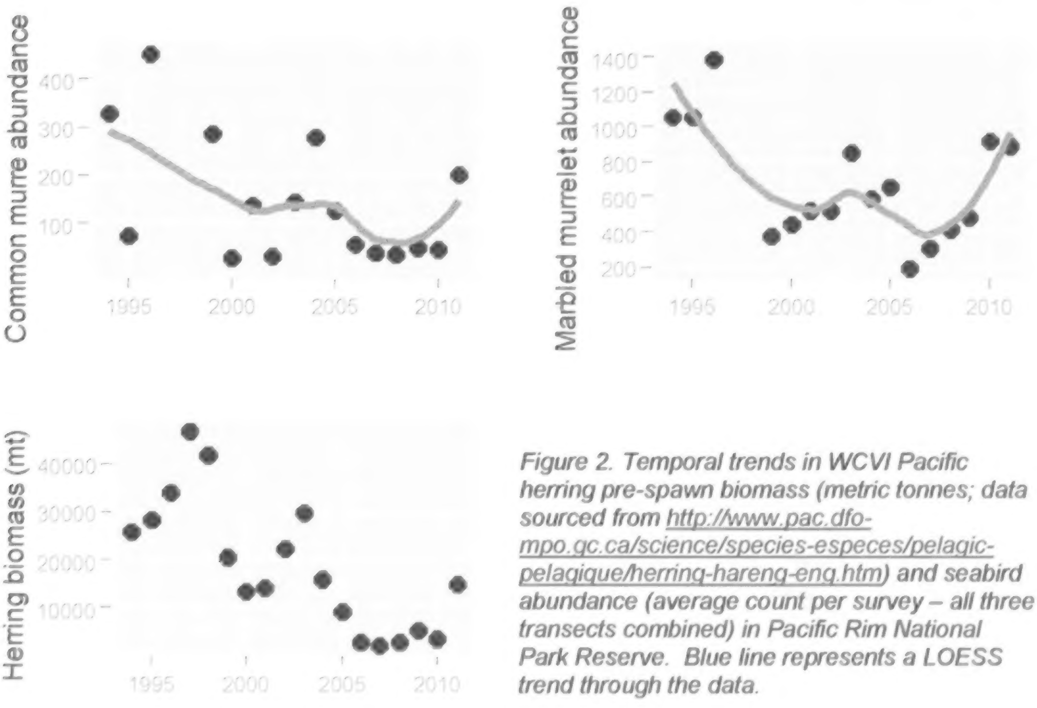

Figure 2. Temporal trends in WCVI Pacific herring pre-spawn biomass (metric tonnes; data sourced from http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng-eng.htm) and seabird abundance (average count per survey – all three transects combined) in Pacific Rim National Park Reserve. Blue line represents a LOESS trend through the data.

Bivalves

Results are presented for three species of clams: butter (*Saxidomus gigantea*), manila (*Venerupis philippinarum*) and littleneck (*Protothaca staminea*), and two species of oysters: Japanese (*Crassostrea gigas*) and Olympia (*Ostrea conchaphila*) (Table 2).

Table 2. Summary of overall bivalve population trend and recent population trends as determined by the most recent break point in the slope. All slopes are reported. Significant (p<0.05) slopes are coded in red for decreasing populations and green for increasing populations.

SPECIES	Overall trend 1997-2011, slope (se)	Recent Trend	2011 Abundance
Butter clam	0.016 (0.077)	Uncertain for most of 2000s	About average
Littleneck clam	0.013 (0.022)	Declining 2006-10	Above average
Manila clam	-0.124 (0.021)	Mostly declining 2006-11	Among the lowest on record
Japanese oyster	0.032 (0.020)	Uncertain for most of 2000s	About average
Olympia oyster	-0.093 (0.024)	Increasing 2004-11	Below average

The year 2011 saw bivalve abundances similar to 2010. Manila clam remains in a steady decline. We investigated a hypothesis that manila clams might have been displaced from their preferred habitat by introduced varnish clams (*Nuttallia obscurata*), typically found in the higher intertidal zone. However, no statistically significant displacement of manilas down along the intertidal gradient overtime has been detected. Rather they declined uniformly across their tidal distribution and throughout the three study sites (Fig. 3).

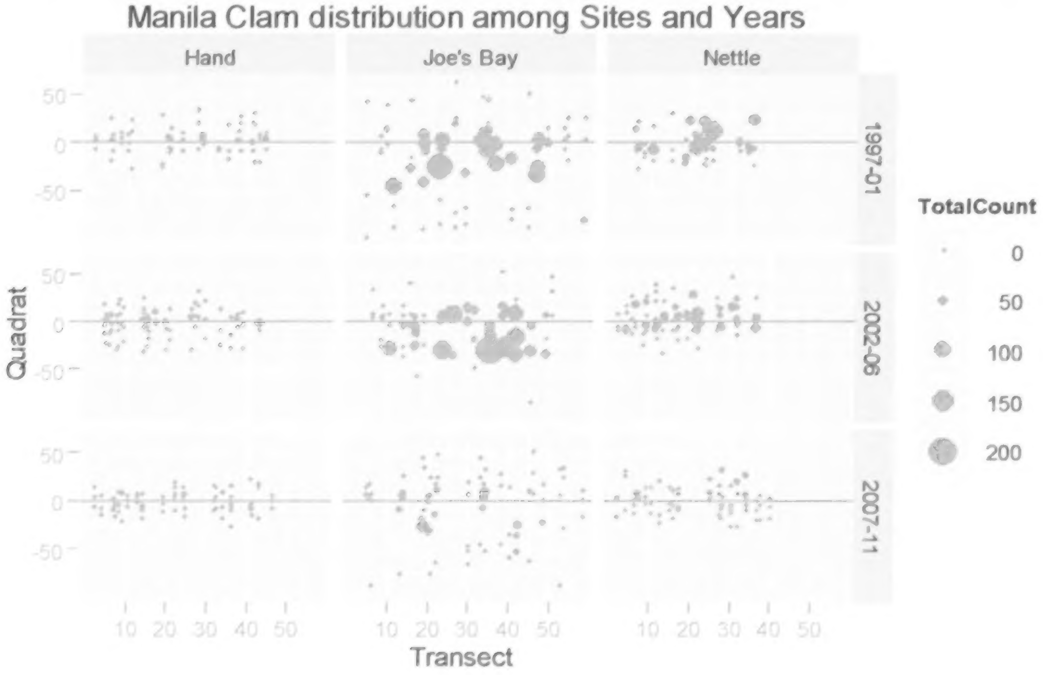

Figure 3. Spatial distribution of manila clams relative to the mid-intertidal line (red line) at three mudflats in Pacific Rim National Park Reserve (Broken Group Islands Unit) among three time periods. Sample units represent 0.25 m^2 plots sampled to 15 cm depth. Quadrat and transect represent the position of a sample in metres across and along the intertidal mudflat respectively.

The introduced Japanese oyster numbers fluctuated, but overall remained stable through the past 7 years and 2011 has seen average numbers. The native Olympia oyster has declined precipitously relative to the start of the sampling program and the overall population trend is still negative. Since 2004, however, there has been a recovery in the species abundance. Bivalves are known to have sporadic recruitment patterns (http://www.pac.dfo-mpo.gc.ca/science/species-especes/shellfish-coquillages/clam-palourde/index-eng.htm) that depend on different biotic factors such as standing stocks, larval supply or epibenthic predation, as well as changes in environmental conditions such as water temperature (Philippart et al. 2003), and air temperature in the winter (Gillespie 1999), and therefore are difficult to predict (Strasser et al. 2003).

Eelgrass fish community

For these analyses several species were combined into broad taxonomic groups and their joint abundances were analysed for temporal trends among Barkley and Clayoquot Sounds, and effects of six covariates measured in situ (SST, SSS, fluorescence, nitrate concentration, eelgrass (*Zostera marina*) biomass and eelgrass epiphyte load). The groups were rockfishes (three species numerically dominated by the black rockfish *Sebastes melanops*), flatfishes (five species dominated by the English sole *Parophrys vetulus* and speckled sanddab *Citharichthys stigmaeus*), greenlings (four species dominated by the kelp greenling *Hexagrammos decagrammus*), eels (nine species dominated by saddleback *Pholis ornata*, crescent *Ph. laeta*, and penpoint *Apodichthys flavidus* gunnels and the snake prickleback *Lumpenus sagitta*) and seaperches (dominated by the shiner perch *Cymatogaster aggregata*). Total species richness was tested for temporal trends as well. Individual patches of eelgrass (hereafter meadows) were treated as random factors. Results of the analyses are summarized in Table 3.

*Table 3. A summary of Generalized Linear Mixed Models (GLMM) relating eelgrass fish abundance and species richness (log+1 transformed) to a set of temporal and in situ environmental predictors (Year, Region (Reg, Barkley or Clayoquot Sound – data from both regions were combined in the analyses), Year x Region interaction (YxR), sea surface salinity (SSS, ppm), sea surface temperature (SST, °C), fluorescence (Fl), nitrate (Ntr, µM), eelgrass biomass (EBM, gm-2), eelgrass epiphyte load (EEL, gm-2)). Parameter coefficients (Standard Error) are given for only significant predictors from the final (reduced) model; "ns" indicates non-significant predictors For all continuous predictors both linear and second order polynomial terms were tested; in the table, coefficients of quadratic terms are denoted with "**"*

SPECIES GROUP	Year	Reg	YxR	SSS	SST	Fl	Ntr	EBM	EEL
Species richness	-0.39 (0.10)	ns	ns	ns	ns	ns	ns	-0.028 (0.009) 4.76e-05** (2.04e-05)	ns
Rockfishes	ns	ns	ns	ns	ns	ns	ns	ns	-0.024(0.014) 1.86e-04** (9.01e-05)
Flatfishes	ns	ns	ns	ns	ns	ns	ns	-0.29(0.11) 5.68e-04** (2.17e-04)	ns
Greenlings	ns	ns	ns	ns	ns	0.17(0.07) -0.012** (0.005)	ns	-5.53e-03** 1.14e-05 (5.89e-06)	ns
Eels	250.2(47.9) -0.062** (0.012)	1.26 (0.33) [CS]	ns	ns	ns	ns	ns	ns	-0.021 (0.008) 1.35e-04** (6.03e-05)
Seaperches	ns	ns	ns	ns	1.91(0.45) -0.056** (0.015)	ns	ns	ns	ns

The following general points are of note: (1) regional (Barkley vs Clayoquot Sound) trends are synchronized, suggesting an overriding effect of global environmental drivers (e.g. oceanographic conditions); meadow explain up to 60% of random variability in fish numbers, which would imply a strong effect of meadow-specific properties (area, adjacent habitat, substrate, etc) on fish abundance; most groups have been stable over the study period, although broad fluctuations were often observed (e.g. Fig. 4); eelgrass properties (biomass or epiphyte load) come up most often as important predictors, as indeed would be expected for a community associated with eelgrass habitat.

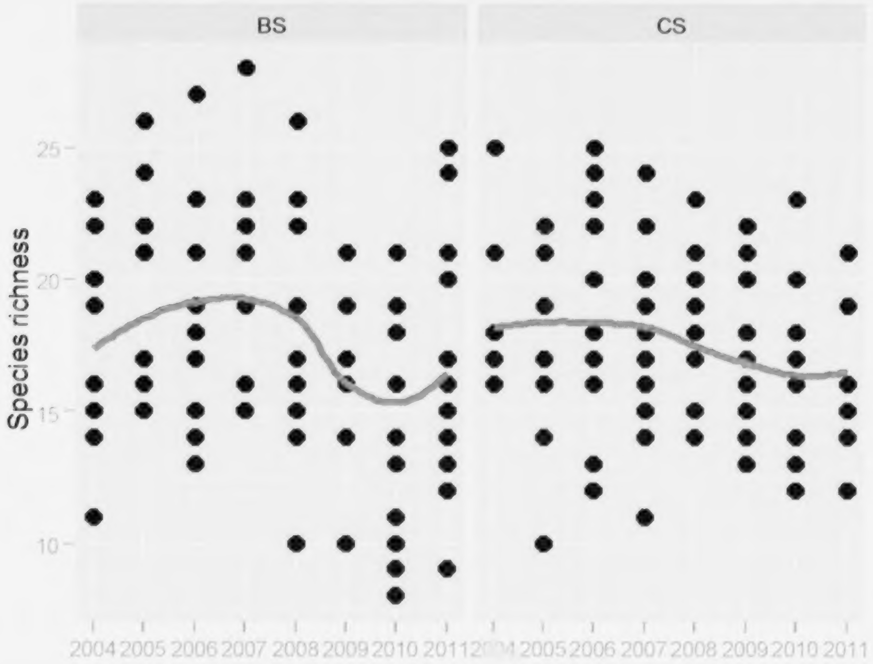

Figure 3. Temporal trend in the species richness of eelgrass fish communities in Barkley (BS) and Clayoquot (CS) Sounds off the West Coast Vancouver Island. Individual dots represent values per site (eelgrass meadow) per year. Blue line represents a LOESS trend through the data.

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3.2.12 Seabird breeding on Triangle Island in 2011: A successful year for Cassin's auklets

Mark Hipfner, Environment Canada

Triangle Island Background and Species Natural History

Marine birds can be effective indicators of the state of marine ecosystems because they gather in large and highly visible aggregations to breed and because, as a group, they feed at a variety of trophic levels (zooplankton to fish). Seabird breeding success is closely tied to the availability of key prey species, and as a result, can vary widely among years, depending on ocean conditions. Triangle Island (50°52' N, 129°05' W) in the Scott Island chain off northern Vancouver Island, supports the largest and most diverse seabird colony along the coast of British Columbia. Since 1994, researchers from the Centre for Wildlife Ecology (a collaboration between Environment Canada and Simon Fraser University) have visited Triangle Island to collect annual time-series information on seabird demography and ecology. This report presents key indicators of seabird breeding at Triangle Island in 2011, and places 2011 results within the context of the 1994-2010 time series.

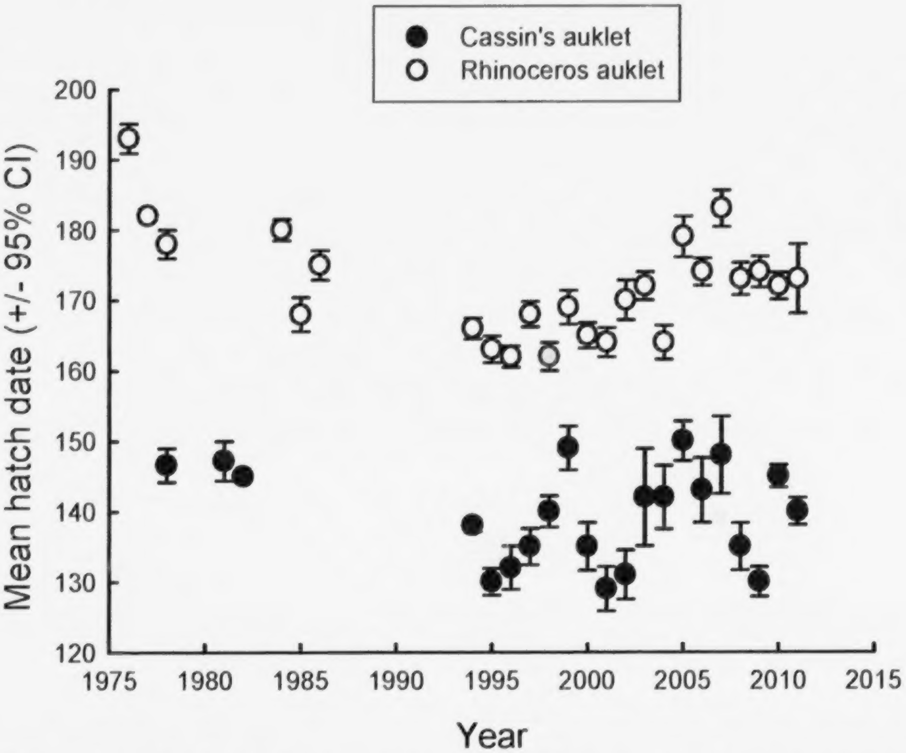

Figure 1. Timing of breeding for two focal seabirds – zooplanktivorous Cassin's auklet and more piscivorous Rhinoceros auklet - on Triangle Island, British Columbia, 1976-2011. Timing of breeding in 2011 was close to long-term averages in both Cassin's auklets and Rhinoceros auklets.

Timing of breeding

Variation in the timing of avian breeding is determined primarily by female condition prior to and during the period of egg formation, which is itself related to food availability early in the season. Over the last 17 years, Cassin's auklets in general have tended to lay earlier in cold-water years and to breed more successfully as a result. But in 2011, timing of breeding in Cassin Auklets was close to the long-term average (Fig. 1) despite that the ocean was relatively cold. For

Rhinoceros Auklets, timing of breeding in general has remained consistent in recent years, including 2011, and close to long-term averages (Fig. 1).

Breeding success

The mean mass at 25 days of age (a new metric being used beginning this year) of all Cassin's Auklet nestlings was above the 1996-2010 average in 2011 – and a marked contrast to 2010 (Fig. 2). In general, the auklets' offspring grow more quickly and fledge at heavier masses in cold-water years, because timing of their hatching is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*. Thus, the above-average, 25-day mass was expected based on the cold spring sea-surface temperatures in 2011. Unfortunately, diet data for 2011 are unavailable at time of writing.

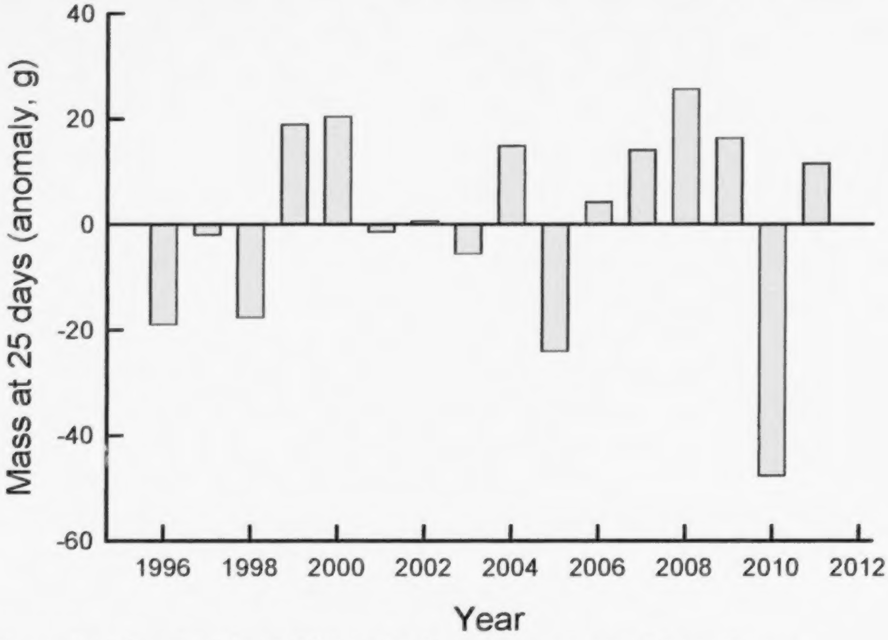

Figure 2. Mass of nestling Cassin's Auklets at 25 days of age, averaged for each year

References

Scott Islands Marine Wildlife Area

Canadian Wildlife Service bird monitoring in BC

Environment Canada Contact: Mark Hipfner (mark.hipfner@ec.gc.ca)

3.2.13 Ocean acidification off southwest British Columbia

Debby Ianson, Fisheries and Oceans Canada

Global oceans are becoming more acidic due to increasing carbon dioxide. Much of the extra CO_2 released by burning fossil fuels ends up in the oceans, increasing the dissolved inorganic carbon concentration (DIC). As DIC increases, the relative proportions of carbon species shift (specifically from the carbonate ion to the bicarbonate ion), resulting in an increase in acidity and a decrease in pH. pH is a measure of acidity on a logarithmic scale. Lower pH indicates more acidic water. At present the global average pH of seawater is 8.1, but this surface value may vary significantly with region. Since the beginning of the industrial era this pH has decreased by 0.1, and represents an increase in acidity of 30%. By the year 2050, pH is projected to decrease by 0.4 (Orr et al. 2005). The decrease in pH is a threat to organisms that produce calcium carbonate shells, especially cold-water corals whose shells are of aragonite, a relatively more soluble form of carbonate (The Royal Society, 2005).

Deep water in the North Pacific Ocean already has the most acidic water in the global ocean. Summer upwelling off southwest Vancouver Island causes low-pH, intermediate-depth water from 100 to 200 metres below surface to come up into the ocean surface layer. The upwelled water is high in nutrients and DIC and so is lower in pH. However this DIC is quickly drawn down by primary producers, and so the exposure of surface water on the shelf to low pH water is expected to be intermittent. To date there have been no *in situ* studies of the effect of this exposure on the local organisms.

There are no complimentary winter observations at present, although because of colder surface temperatures, winter mixing, higher DIC and lower primary production, there may be corrosive surface water over the shelf at this time of year. Given the lack of winter observations, Fig. 1 from Ianson and Allen (2002) presents model simulations of present-day pH on the continental shelf of southwest Vancouver Island. Near-bottom pH is lower than found in the upper mixed layer throughout the year.

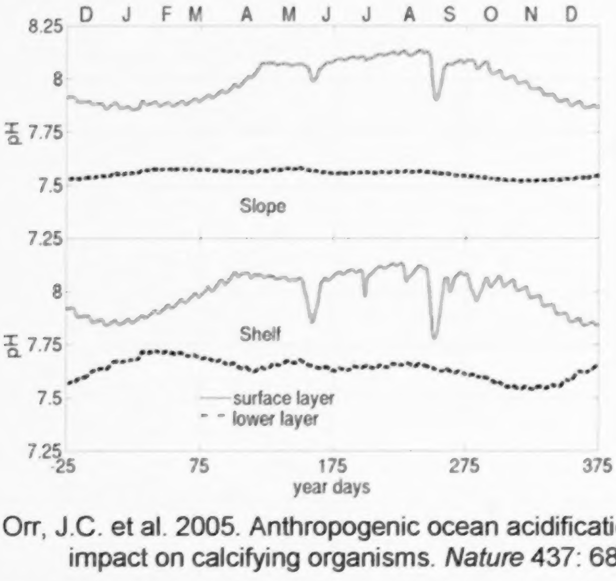

Figure 1. Model simulation of the oceanic pH on the continental shelf and slope of southwest Vancouver Island in a typical year. Bottom depths of these two locations are 100 and 600 metres, respectively. The green line represents pH in the ocean surface mixed layer. The black line represents pH below this mixed layer. The count of year days extends beyond the ends of a typical year to show the annual cycle more clearly.

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3.2.14 Oxygen concentrations on the continental shelf

Bill Crawford and Angelica Peña, Fisheries and Oceans Canada

Oxygen concentrations on the continental shelf of British Columbia are generally lowest on the southwest Vancouver island shelf near the ocean bottom. Oxygen concentrations have been observed to drop below 1 millilitre per litre (mL/L) in this region at or below 120 metres depth, and even lower at the bottom in some fjord-type inlets where oxygen is naturally low. A concentration of 1 mL/L is about 50 μM at 6 °C.

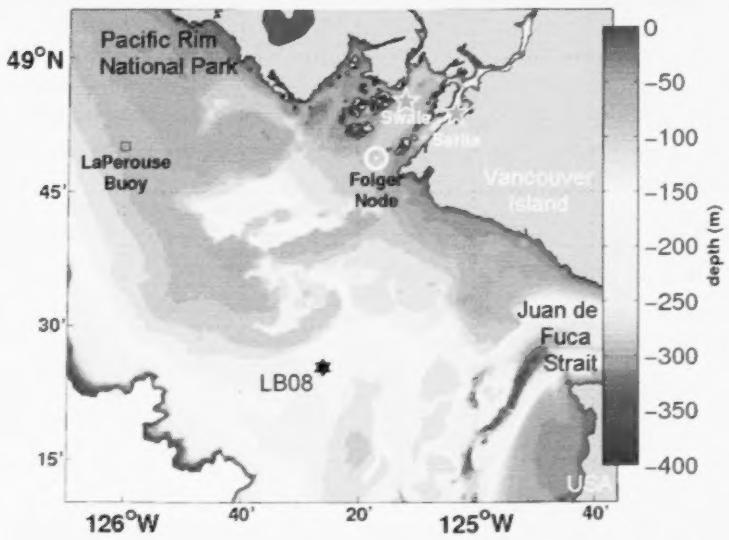

Figure 1. The continental shelf off southwest Vancouver Island, with colours denoting depth of bottom.

On the continental shelf of Vancouver Island, the lowest concentration of oxygen is normally in late August and September near the ocean bottom in the region of station LB08, shown in Fig. 1. This conclusion is based on a study of archived and ongoing measurements of oxygen on the continental shelf in British Columbia (Crawford, W.R. and Peña, M.A., unpublished manuscript).

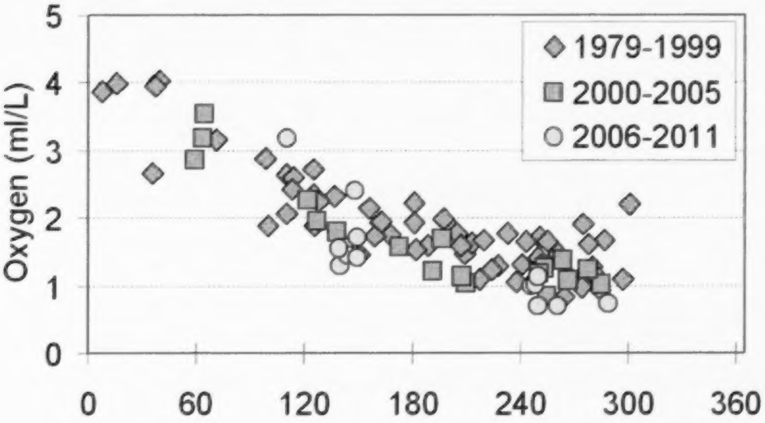

Figure 2. Graph of all individual samples of oxygen concentration collected near the ocean bottom within 10 km of station LB08 from 1979 to 2011. The X-axis is day of the year. Day 122 is May 2; day 244 is Sept. 1. Colour and style of symbols denote the years of sampling. Figure from W.C. Crawford and M.A. Peña (unpublished manuscript).

Fig. 2 shows all measured values sorted by day of the year. Lowest concentrations are from lat August to early October. Red and Blue symbols of Fig. 2 reveal that oxygen at this sampling station was generally lower in the years 2000-2011, and lowest from 2005 to 2011. The lowest concentration of the entire time series was 0.7 mL/L in 2006 and again in 2009. Oxygen concentration was 1.0 and 1.1 ml/L in September of 2010 and 2011, respectively.

An analysis of the trend in near-bottom oxygen concentration at station LB08 reveals a decline since 1979 at a rate of 0.019 ml/L per year. On the continental slope off southwest Vancouver

Island (Fig. 1) this rate of decline at 200 metres depth was calculated as 0.025 ml/L per year (Crawford, W.R. and Peña, M.A., unpublished manuscript). The depth of 200 metres is significant because water from this depth on the continental slope upwells onto the bottom of the continental shelf in summer. In general, seawater at 200 metres depth on the continental slope flows in from the south along the continental slope, and also mixes with sub-surface seawater to the west. Both of these water masses have experienced a decline in oxygen since the early 1980s, which is the suspected cause of decreasing oxygen concentrations in deep waters off southwest Vancouver Island.

NEPTUNE Canada installed several continuously recording ocean sensors west of British Columbia in 2009. For oxygen studies the most relevant station is at the Folger Node shown in Fig. 1, which has recorded since October 2009. Temperature and oxygen sensors are at about 100 metres depth, just above the bottom, so oxygen levels are higher than at LB08 where the ocean depth is about 50 metres deeper. Fig. 3 shows daily average oxygen and temperature at this station. Readers can update this time series using this link [http://www.neptunecanada.ca/], and requesting an account to view all observations.

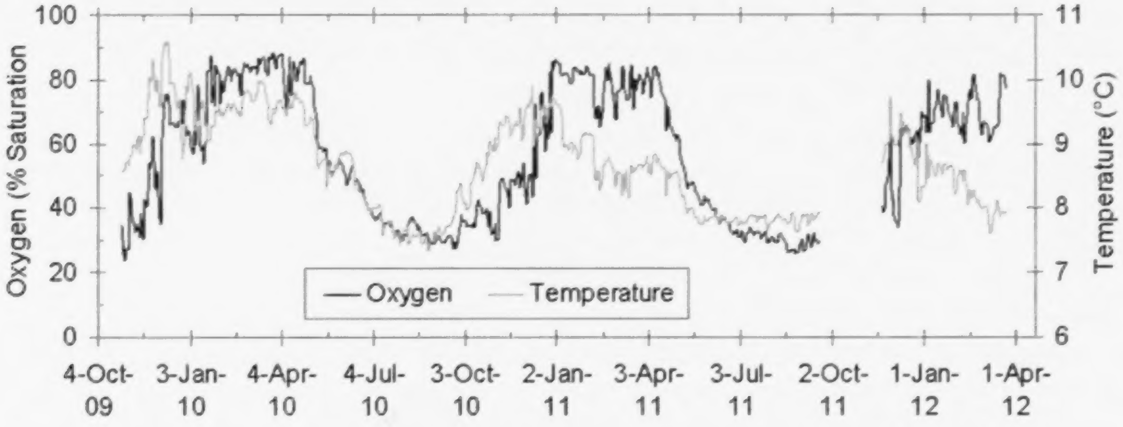

Figure 3. Daily averages of oxygen (percent saturation) and temperature at Folger Passage in the entrance to Barkley Sound, from October 2009 to March 2012. Station and real-time data access are provided by NEPTUNE Canada.

This time series reveals typical features of the British Columbia continental shelf. Coldest bottom water is in summer, not in winter. Deeper, cold, low-oxygen waters upwell in summer, forced by the prevailing winds from the north and northwest. In winter, storm winds blow from the south and push warmer, oxygen-rich surface water onto the continental shelf and also mix and downwell it toward the bottom. Notice that the water in January to March 2010 was much warmer than in the following winters, due to stronger southerly winds in early 2010 compared to 2011 Finally, oxygen concentrations were somewhat lower in the most recent winter.

3.2.15 Oil in Canadian waters

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Background

According the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 2007), shipping vessel activity is responsible for approximately 37% (457,000 tonnes/yr) of the total estimated oil input into the global marine environment (1,245,000 tonnes/yr), which includes oil input from natural seeps. Operational discharges of waste oil contribute 45% of the total estimated oil pollution attributable to shipping, while accidental discharges or "discharges" contribute only 36%. Operational discharges typically occur in smaller quantities than accidental oil spills, yet are responsible for a larger proportion of oil pollution attributable to shipping. Although accidental spills can be large and considered catastrophic in terms of environmental impacts, spill volume is not considered as important a determinant of impact, at least in terms of seabird mortality (Burger 1993), as timing and location are. For example, approximately 300,000 seabirds are killed each year from illegal discharges of waste oil from vessels passing through an area of the southwestern shore of Newfoundland, despite the absence of documented discharges (Weise and Robertson 2004).

Operational discharges can be both accidental or intentional, but both are often illegal according to Canadian legislative acts that reflect Canada's ratification of the International Convention for the Prevention of Pollution from Ships 1973/1978 (MARPOL 73/78: International Maritime Organization). Because of their size and clandestine nature, operational discharges are often undetected or detected as "mystery" discharges, providing a "chronic" level of background oil pollution in marine environments. The authors of this report are members of the Oil in Canadian Waters (OCW) research working group, which is a multidisciplinary team of researchers from various academic and governmental research organizations that was formed to address this issue using a spatial risk analysis model approach. In this approach, spatially explicit risk is assessed as the combination of the likelihood of a discharge occurring in a given area and the environmental consequence of a discharge should one occur.

We report on preliminary results from our modelling of the likelihood of oil discharges occurring in a given area. Our modelling approach involves 1) the spatial and temporal definition of patterns of discharges as detected by the National Aerial Surveillance Program (NASP), which is a Transport Canada program dedicated to monitoring marine oil discharges and enforcement of Canadian pollution legislation, and 2) predictive modeling with potential explanatory factors to better understand underlying processes driving patterns defined above.

Oil discharge likelihood

Regional trends in observed patterns

We based our modelling on data collected since late 2006 after aircraft in the program were outfitted with the Maritime Surveillance System 6000 (MSS6000: Swedish Space Corporation). The MSS6000 is a network of remote sensing instruments (Side-Looking Airborne Radar [SLAR], Infrared and UV sensors, and high resolution cameras) with central server that geo-rectifies and archives all data collected. Our models are based on data collected by NASP in the Pacific, Great Lakes – St. Lawrence, Maritimes, Newfoundland-Labrador, and Eastern Arctic regions of Canada (Fig. 1). Of the total NASP surveillance effort in hours, approximately 29% is allocated to the Pacific, 13% in the Great Lakes – St. Lawrence, 21% in the Maritimes, 30% in Newfoundland-Labrador, 7% in the eastern Arctic regions. The highest proportion of oil pollution discharges was detected in the Pacific region (51% of total detected), followed by the Maritimes region (30% of total sightings), Newfoundland-Labrador (8%), Great Lakes – St. Lawrence (2%) and eastern Arctic (1%) regions. The detected oil discharges are smaller in the Pacific region where the average discharge volume is 14 litres, whereas average volume is 42 litres in the

Maritimes, 74 litres in Newfoundland-Labrador, and 94 litres in the Great Lakes – St. Lawrence regions. This suggests that the underlying processes or causes of oil pollution in the Pacific region differ from those in the other regions under NASP surveillance.

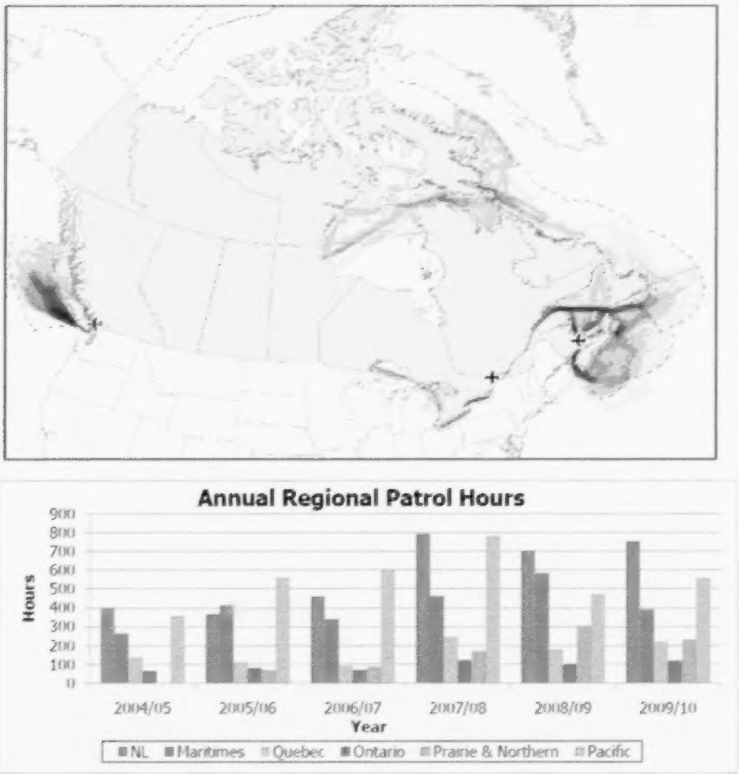

Figure 1: Summary of National Aerial Surveillance Program effort. The upper panel shows relative spatial distribution of effort throughout Canada (cumulative hours from 2006-2010: darker areas are exposed to higher surveillance effort), and the bottom panel shows total hours per region per year (reproduced from NASP 2010). Aircraft are stationed at areas symbolized by aircraft on upper panel.

Spatial patterns of discharges observed in Pacific Region

Surveillance effort is spatially heterogeneous and for this reason, we have to correct for effort in order to define spatial patterns of detected oil discharges in the Pacific region (Fig. 2). To do this, we divided the region into 5 by 5 km grid cells and summarized NASP effort and discharges detected per cell, and estimated the likelihood of detecting pollution as the number of detections per number of visits by NASP per cell. When correcting for NASP effort, we found that the highest relative likelihood of detecting oil discharges occurred close to shore and in particular in Strait of Georgia, the inside passage of the central coast, near Prince Rupert, and in Alberni Inlet (Fig. 2, right). This suggests to us that local ship movements or coastal maritime activities (i.e., recreational crafts, tugs, fisheries) and facilities (i.e., marinas) are more likely associated with general spatial patterns of detected oil discharges in the Pacific region.

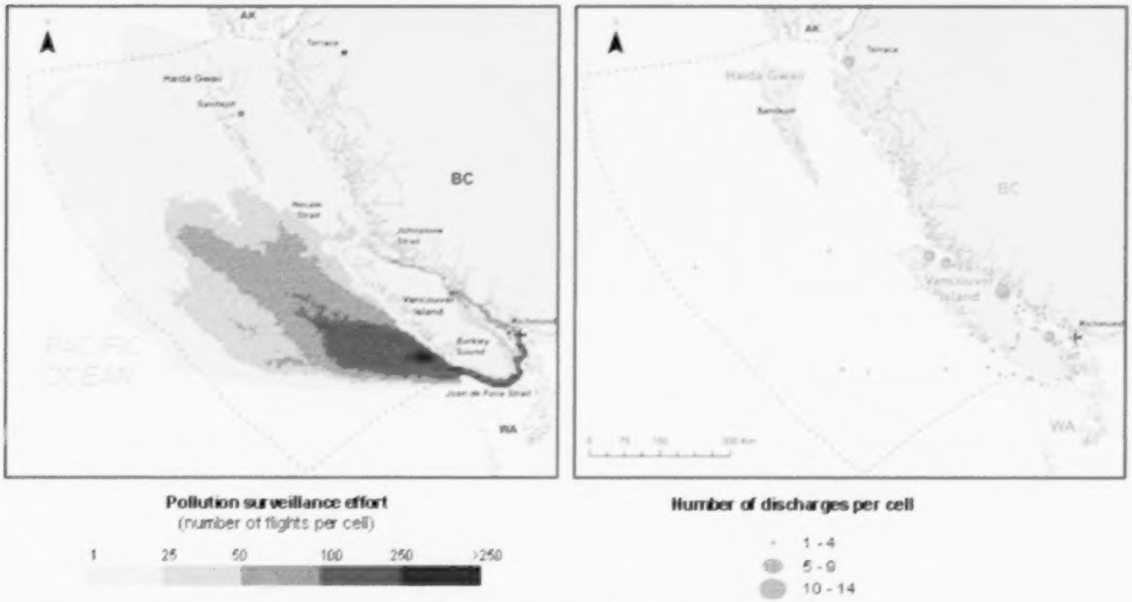
AK
BC
WA
PACIFIC OCEAN
Haida Gwaii
Vancouver Island
Pollution surveillance effort
(number of flights per cell)
1
25
50
100
250
>250
Number of discharges per cell
1 - 4
5 - 9
10 - 14

Figure 2: NASP effort and corrected oil discharge detection in the Pacific Region.

Multivariate predictive modelling

We use geographically weighted regression to identify potential variables associated with oil discharge patterns as detected by NASP, and to help fill in surveillance gaps by predicting patterns where surveillance effort may be low. Predictor variables include distance to shore, density of marinas, major ports, and an array of variables defining various components of shipping intensity (measured as cumulative hours per cell). Shipping information has been parsed out into vessel type (for example see Fig. 3), vessel age, length overall, and country registration (or "Flag State"). Shipping data were provided by the Marine Communications and Traffic Services (MCTS of the Canadian Coast Guard), and processed by the Marine Activity and Risk Information Network (MARIN: Dalhousie University). Although results are preliminary, we have found that marina densities and intensity of local vessel activity (as opposed to international shipping) generally determine oil discharge patterns in the Pacific Region.

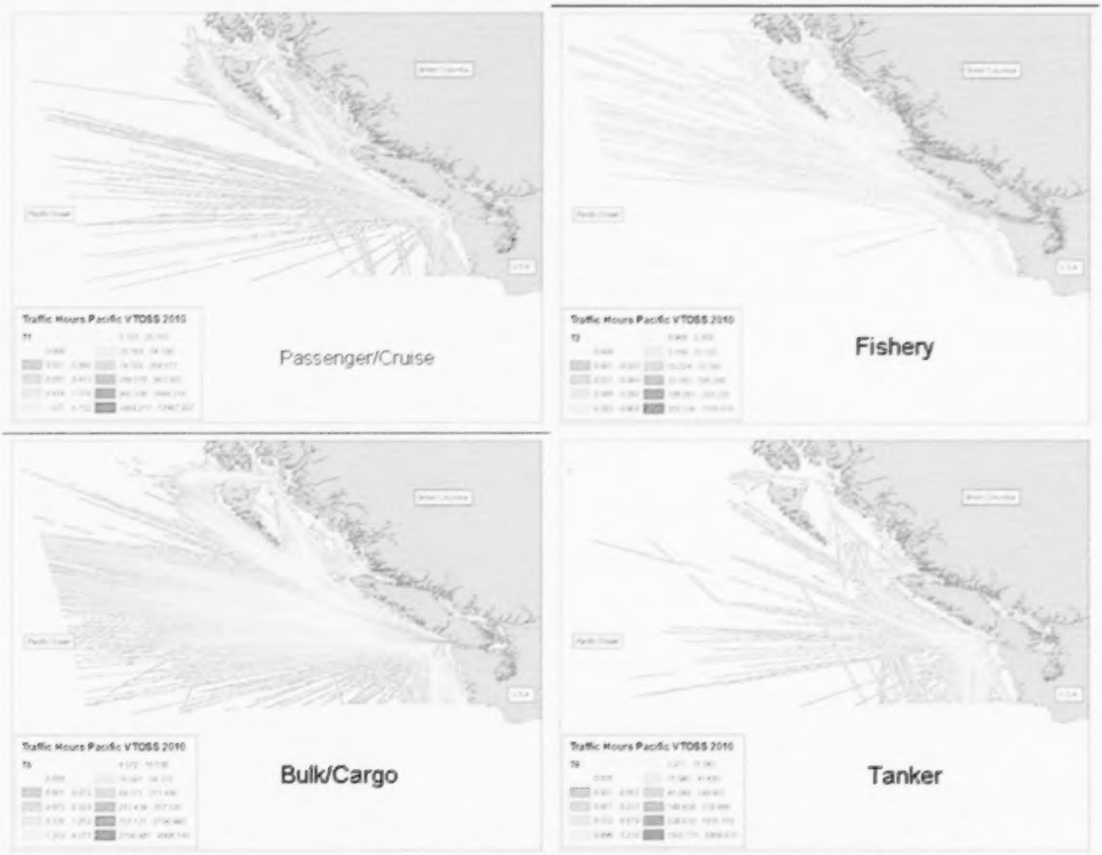
Traffic Hours Pacific VTOSS 2010
Passenger/Cruise
Traffic Hours Pacific VTOSS 2010
Fishery
Traffic Hours Pacific VTOSS 2010
Bulk/Cargo
Traffic Hours Pacific VTOSS 2010
Tanker

Figure 3. An example of GIS layers summarizing shipping intensity per cell by vessel type.

Summary

This project provides important information regarding oil discharge patterns and possible underlying factors determining these patterns, which could act as a baseline for detecting temporal trends associated with changes in policy and industrial development that will likely occur along the Pacific coast of Canada. Temporal trends can be estimated at different scales because this information is spatially explicit with a high resolution (5x5 km cells). Preliminary results from this project, along with summary results from NASP reports dating back to 2004 (NASP 2010), and independently collected data reflecting oil discharge rates (i.e., beached bird surveys), suggest that NASP presence is having a deterrent effect on oil pollution rates, at least in some areas of the Pacific (Juan de Fuca Strait and over the continental shelf west of Juan de Fuca Strait: O'Hara et al. 2009).

Acknowledgements

We thank Transport Canada – Research and Development for funding this programme over the last two years, Environment Canada for providing in-kind support. P.D. O'Hara is indebted to the Institute of Ocean Sciences, Ocean Sciences Division (DFO) for in-kind support. All OCW modelling are based on data provided by Transport Canada – National Aerial Surveillance Program (NASP) and the Department of Fisheries and Oceans – Canadian Coast Guard.

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NASP. 2010. National Aerial Surveillance Program statistical report, 2004/2005 to 2009/2010: protecting our waters. Internal report for Transport Canada.

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2.3 SALISH SEA

2.3.1 Colder and fresher subsurface waters in the Strait of Georgia

Diane Masson and Patrick Cummins, Fisheries and Oceans Canada

Fig. 1 shows the location of the Nanoose station in the central deep basin of the Strait of Georgia where, since 2005, temperature contours have been measured (Fig. 2). In the spring and early summer of 2011, cold, sub-surface intrusions slightly lowered temperatures throughout the water column of the strait.

Fig. 3 gives the temperature anomalies over the last 7 years at the Nanoose station relative to the 30-year average computed over the period 1971-2000. It shows that the slightly warmer waters in 2010 have been replaced in 2011 by colder waters with small negative anomalies.

In Fig. 4, monthly surface salinity negative anomalies measured at Entrance Island (see Fig. 1 for location) as well as monthly Fraser River discharge (Morrison et al., 2012) are presented. Both time series have been normalized and low-pass filtered with a 9-month triangular filter. The salinity anomalies at the surface of the strait are closely related to Fraser River discharge anomalies, with a correlation coefficient r=0.77. During most of 2011, large freshwater influx from the river has resulted in fresher than average surface waters.

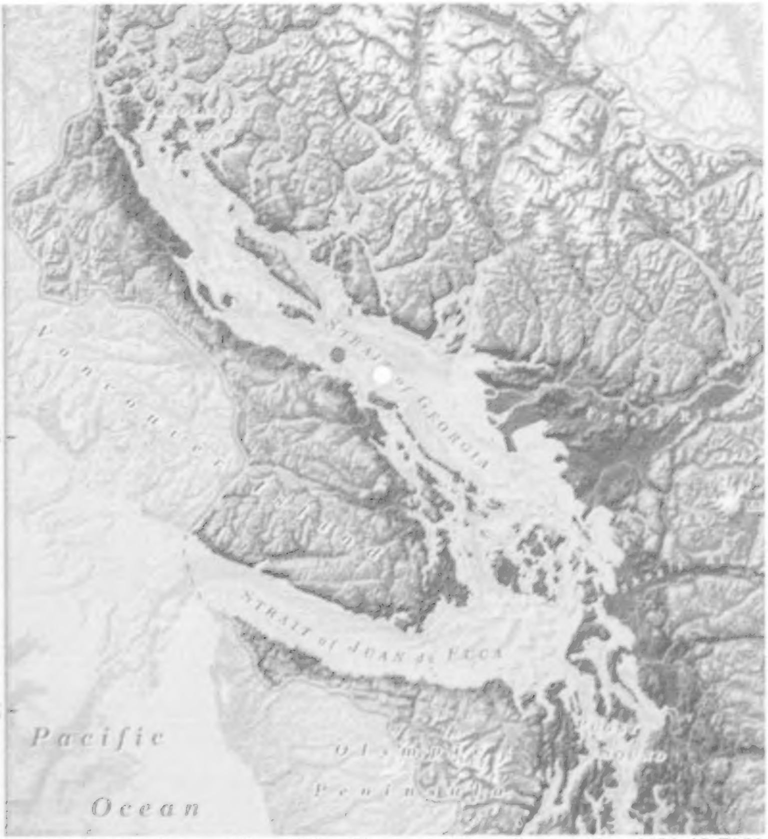

Figure 1. The red dot indicates the position of the Nanoose sampling station (49° 18.7′ N, 124° 2.7′ W), and the yellow dot the Entrance Island lighthouse station (49° 13′ N, 123° 48′ W).

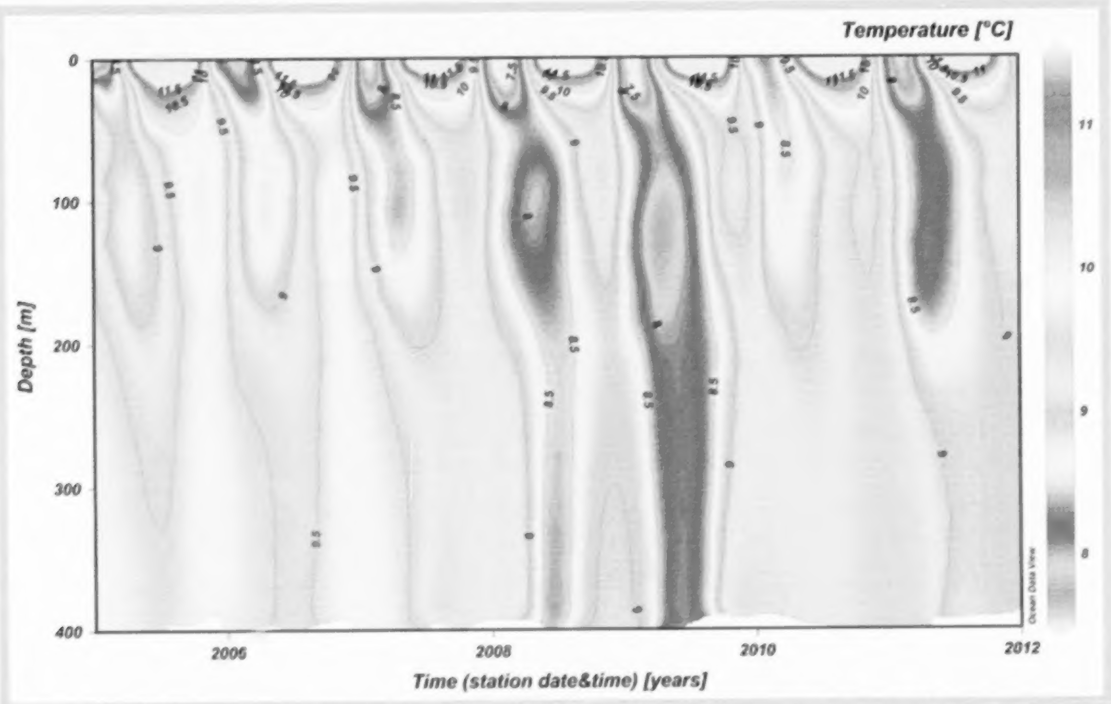

Figure 2. Contours of temperature (°C) measured at the Nanoose station (central Strait of Georgia) since 2005.

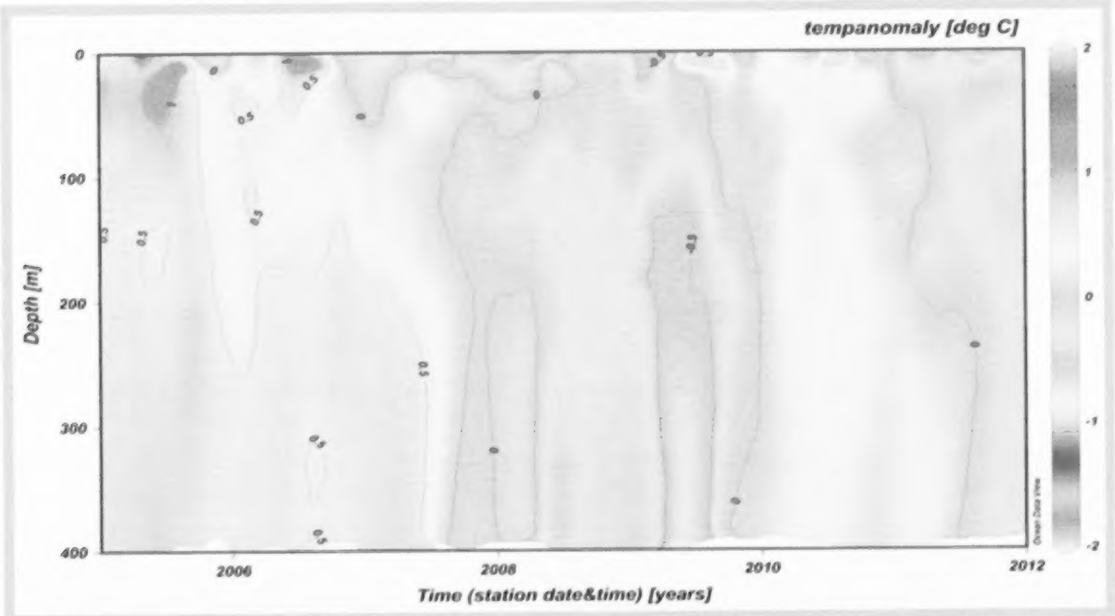

Figure 3. Contours of temperature anomalies (°C) measured at the Nanoose station, for the period 2005-2011. Anomalies are computed relative to the climatological mean for 30-year period 1971-2000.

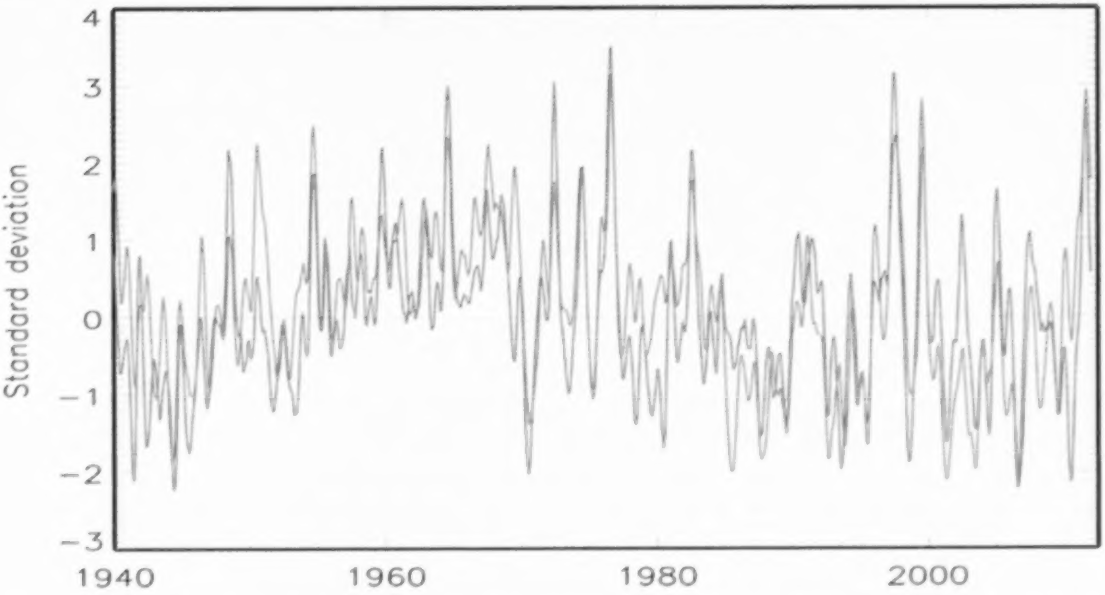

Figure 4. Normalized negative salinity anomalies measured at the Entrance Island (blue) and anomalies of Fraser River discharge (red), for the period 1940-2011. Anomalies are computed relative to the climatological mean for 30-year period 1971-2000. A negative salinity anomaly indicates saltier water.

Reference

Morrison, J., Foreman, M.G.G., and Masson, D. 2012. A method for estimating monthly freshwater discharge affecting British Columbia coastal waters. *Atmosphere-Ocean* 50(1): 1-8.

2.3.2 VENUS observes robust annual cycles, with slightly cooler 2011

Richard Dewey, Victoria Experimental Network Under the Sea (VENUS), University of Victoria

The Victoria Experimental Network Under the Sea (VENUS), the coastal network of Ocean Networks Canada (ONC), maintains a variety of oceanographic sensors in both Saanich Inlet and the southern portion of the Strait of Georgia. Instrument specifications, locations, and both live and archived data can be found at the project web site, http://www.venus.uvic.ca/. VENUS now maintains four permanent stations, one at 96 m in Saanich Inlet, and three in the Strait of Georgia [referred to as the Central (300 m), East (170 m), and Delta Dynamics Laboratory (108 m)]. At each of these stations VENUS hosts a suite of standard sensors including CTD with dissolved oxygen, inverted echo-sounders, and ADCPs for measuring currents. Over the next two years VENUS is adding surface observations from CODAR stations, BC Ferries, ocean gliders, and a cabled buoy profiling station in central Saanich Inlet.

The CTD data records for 2011 reveal several key features of the oceanographic conditions of the Salish Sea. The longest records (over six years) are from Saanich Inlet (Fig. 1), showing the annual cycles of Oxygen, Density, Salinity and Temperature.

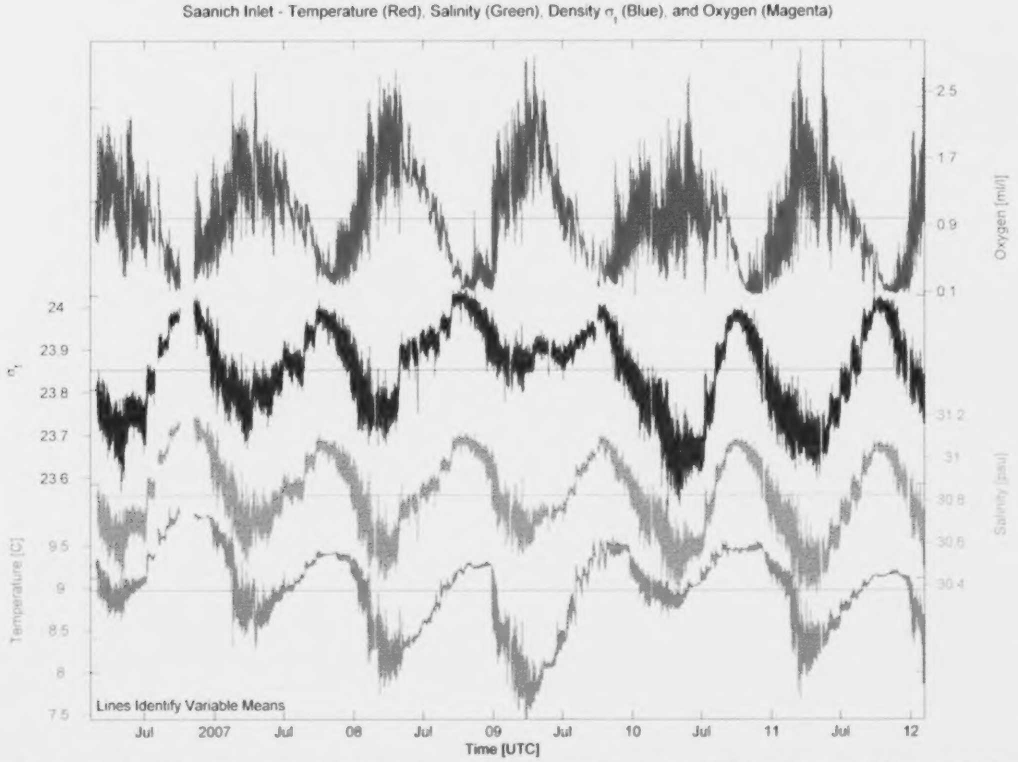

Figure 1. VENUS CTD time series from the Saanich Inlet central Node/VIP location at a depth of 96 m. Top to bottom: Oxygen, Density, Salinity, and Temperature.

In addition to the time series, these plots include horizontal lines for each variable identifying the mean, based on the entire displayed record. These mean values allow for some initial inter-annual comparisons, and should not be taken yet as climatological. The 2011 winter cooling/freshening (Dec 2010 through May 2011) and subsequent summer warming/salinity-increase (June 2011 through October 2011) resulted in a rather "typical" annual cycle, in that the net changes were not extraordinary. However, the mild summer of 2011 resulted in a final temperature rise (November 2011) to only just above (9.2°C) the long-term mean (9.0°C) for this site (SI). Similar CTD trends were recorded at both Node locations in the Strait of Georgia (Fig. 2, East [170m], and Fig. 3, Central [300m]).

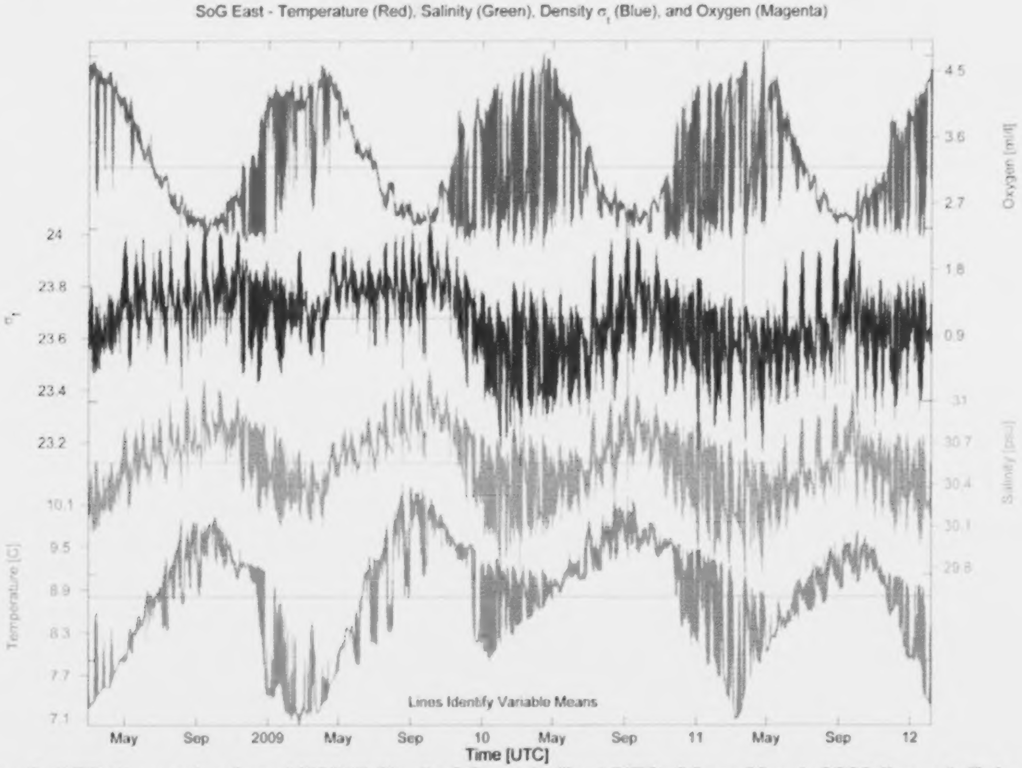

Figure 2. CTD time series from VENUS Strait of Georgia East [170m] from March 2008 through February 2012. Top to bottom: Oxygen, Density, Salinity, and Temperature

The VENUS Strait of Georgia (SoG) East station (Fig. 2) is located just southwest of the Fraser River mouth, at a depth of 170m, which nicely represents a mid-water column perspective. Annual cycles here are evident, onto which are superimposed significant short term variations associated with tidal excursions of water from the south and north. During the winter cooling/freshening period, water from the south tends to be cool and fresh, arriving with flood tides. Water to the north tends to be warmer and saltier, and arrives during ebb tide excursions. During the summer warming/salinity-increase period, water masses residing in the southern reaches of the Strait (closer to Boundary Passage) tend to be warmer and saltier, and arrive on flood tides. Consistent with the Saanich Inlet time series (Fig. 1), both stations in the Strait of Georgia reveal a relatively cool plateau at the end of the summer warming/salinity-increase period (October/November), resulting in a net cool Salish Sea water column when compared to the short record means (horizontal red line). This slightly cool marine condition is consistent with a regional trend driven in part by La Niña conditions since mid 2010.

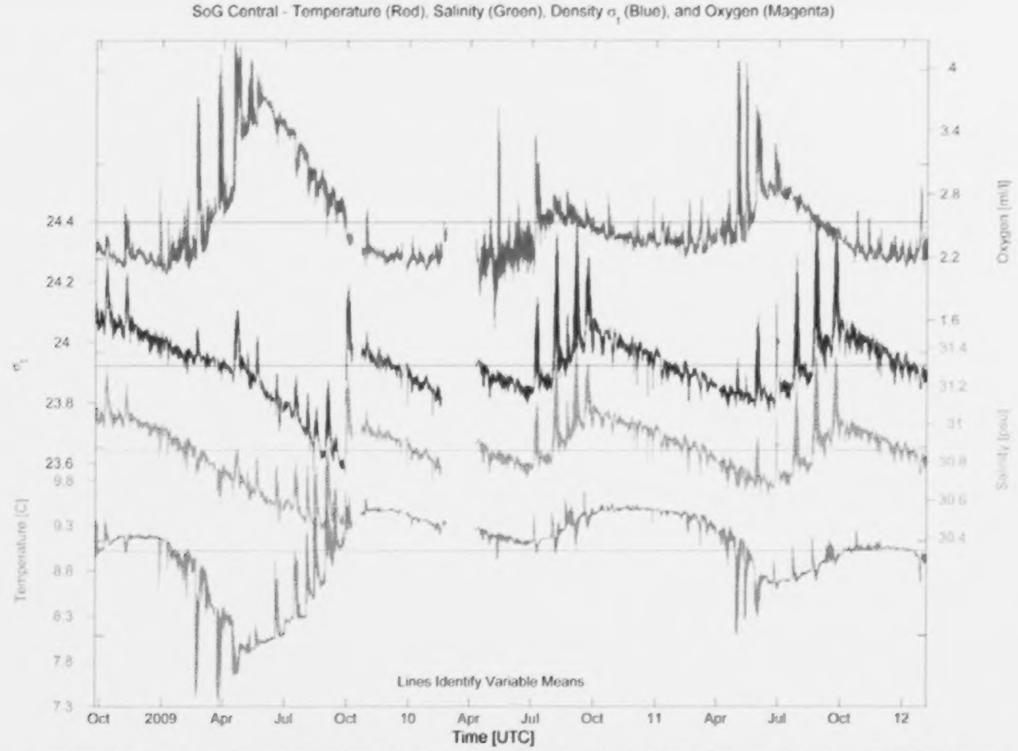

Figure 3. CTD time series from VENUS Strait of Georgia Central (300m) from October 2008 through February 2012. Top to bottom: Oxygen, Density, Salinity, and Temperature.

Top-down Ventilation vs. Deep Water Renewal

At all VENUS sites (e.g. Figs. 1-3) the annual cycle is dominated by two distinct phases. During the winter phase, the core water property (T/S) changes are consistent with a top-down flux, while during the summer phase (T/S) changes are consistent with deep water renewal. During both phases, tidal mixing in the Gulf and San Juan Islands (Haro Strait and Boundary Passage) likely plays an important role in water mass formation/transformation.

As the first order tracer, let us consider salinity as the simplest conserved quantity. Fresh water (low salinity) enters the system near the surface, and during the winter is associated with rainfall and coastal river run-off. In contrast, salty water (high salinity) has a single source, primarily bottom water flowing in Juan de Fuca Strait from the Pacific. During the winter cooling/freshening ("ventilation") phase, surface water conditions (cold and fresh) are mixed downward, causing a reduction in salinity and temperature. During the summer warming/salinity-increase (deep water renewal) phase, dense high salinity (upwelled) water is partially mixed by the tides (becomes slightly warmer), and flows near the sea floor from the West Coast of Vancouver Island into the SI and SoG basins during the weak neap tides, primarily once per lunar month (five salty/dense pulses in 2011, Figs. 1-3). Although not shown here, it should be noted that the transition between the "ventilation" and "deep-water renewal" phases (~May) coincides with the onset of upwelling favourable winds along the west coast of Vancouver Island and the start of the seasonal snow-melt freshet of the Fraser River, which drives an estuarine circulation to help bring in the deep upwelled water through Juan de Fuca Strait.

2.3.3 High phytoplankton biomass observed in the Strait of Georgia

Angelica Peña, Fisheries and Oceans Canada

Nutrients and phytoplankton pigments, chlorophyll-a (chl, an indicator of phytoplankton biomass) and accessory pigments (indicators of phytoplankton community composition), are measured on 5-day cruises 4 times a year in spring (April), summer (June), fall (Sept. to early Oct) and winter (mid-Oct to mid-Nov) along a 20-station transect in the Salish Sea (Fig. 1). In general, upper layer (0-10 m) chl concentrations in the Strait of Georgia are highly variable in spring with >15 mg m^{-3} during phytoplankton bloom events (mid Feb. to April), low during the summer and fall (1-4 mg m^{-3} on average), and lowest (<0.5 mg m^{-3}) during winter. In comparison, no spring bloom events have been observed in Juan de Fuca Strait, and chl concentrations there are significantly lower (<3 mg m^{-3}) than in the Strait of Georgia in spring, perhaps due to strong vertical mixing. On average, similar chl values are found at other times of the year in both regions but they are more variable in Juan de Fuca Strait (Fig. 2).

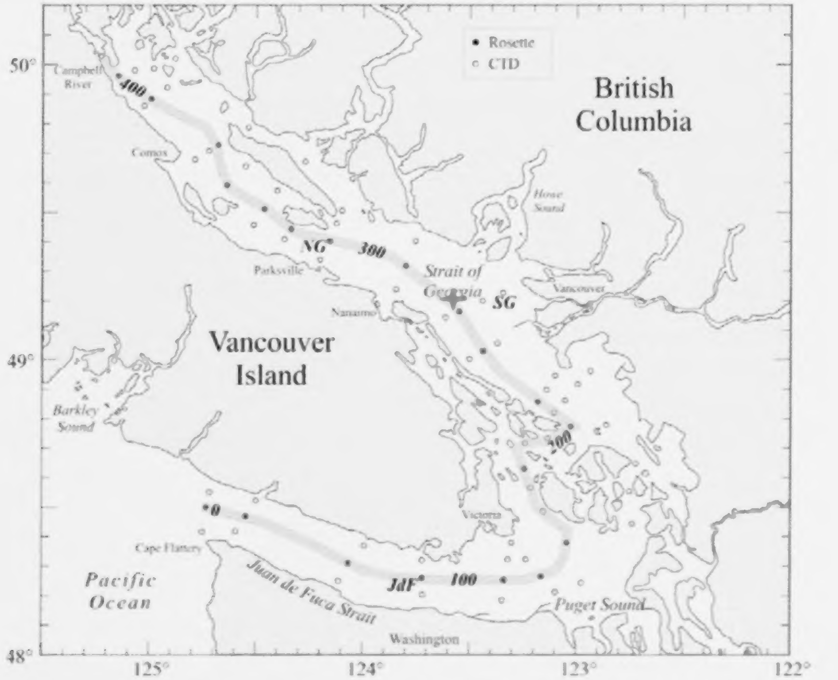
Rosette
CTD
British Columbia
Campbell River
400
Comox
NG
300
Parksville
Strait of Georgia
SG
Nanaimo
Howe Sound
Vancouver
Vancouver Island
Barkley Sound
200
0
Victoria
Cape Flattery
Pacific Ocean
Juan de Fuca Strait
JdF
100
Puget Sound
Washington
50°
49°
48°
125°
124°
123°
122°

Figure 1. Locations of sampling stations in Juan de Fuca Strait and Strait of Georgia region. The thick, shaded line shows the main transect of stations used in Figure 2, with the numbers giving the distance in km from the mouth of Juan de Fuca Strait. The red star shows the location of the station used in Figure 3.

Upper layer nitrate concentrations in 2011 (Fig. 2, left) were within the range of values observed in previous surveys but lower than the 2002-2010 average at most stations in the Strait of Georgia during the fall survey and in Juan de Fuca Strait during the winter survey.

Upper layer chl concentrations in 2011 (Fig. 2, right) were similar to the average values from previous years (2004-2010) in the Juan de Fuca Strait, except for slightly lower concentrations during the summer survey. In the Strait of Georgia, upper layer chl concentrations in 2011 were high during the spring survey (~30 mg m^{-3}) and the summer survey (~10 mg m^{-3}) but similar to those observed in previous years during fall and winter surveys (Fig. 2, right). These upper layer chl concentrations in spring were 2.5 times higher in 2011 than the average from 2004-2010 but similar to the high values observed in some locations in 2009. In the summer survey of 2011, upper layer chl concentrations were the highest so far observed in the Strait of Georgia at this time of the year (~4 times higher than average values from previous summer surveys). Similarly, on June 22, 2012, a MERIS satellite image showed extremely high values of phytoplankton over large areas of the Strait of Georgia, especially near the Fraser River plume (Gower and King 2012, elsewhere in this research document). However, these discrete ship-based observations (5 days, 4 times a year) are not adequate to study year-to-year variability in phytoplankton biomass, since the observed differences in chl concentrations could be as much due to intra-seasonal as to inter-annual variability. To be able to compare among years in the Strait of Georgia, frequent (daily to bi-weekly) observations would be necessary depending on the time of the year.

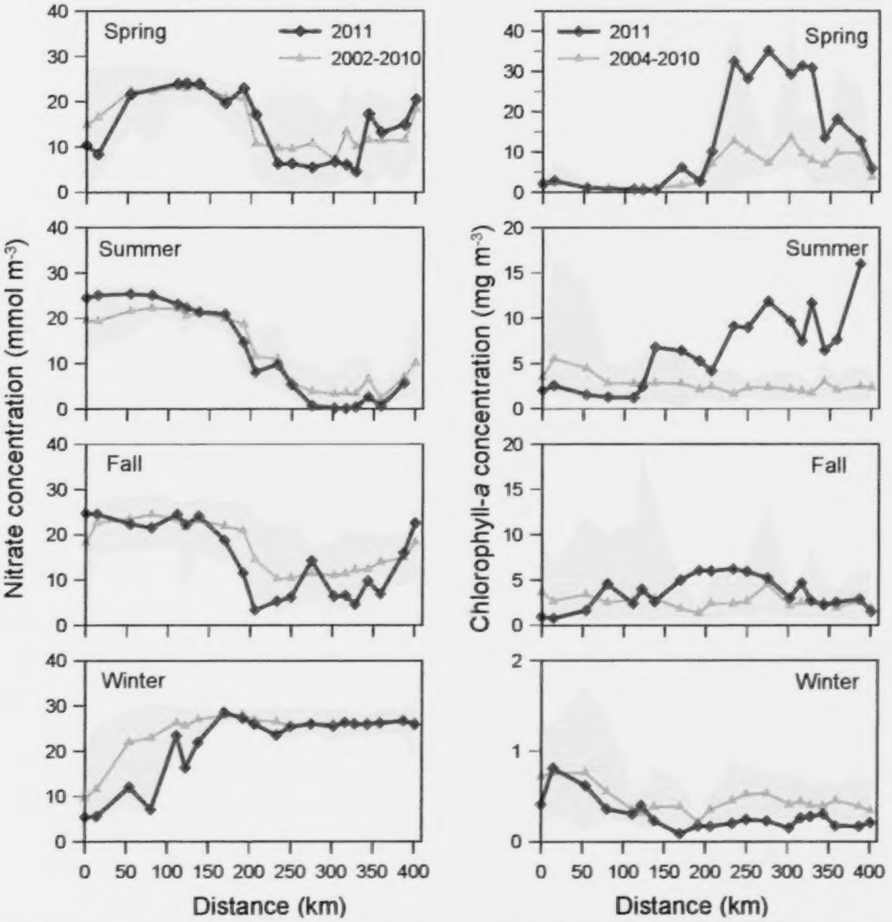

Figure 2. Upper layer nitrate (left panel) and chlorophyll (right panel) concentrations along the main transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer, fall, and winter surveys. Blue diamonds are observations in 2011. Magenta triangles and shaded area denote averages and ranges from 2002 to 2010 for nitrate and 2004 to 2010 for chlorophyll. Numbers along lower axes are cumulative distance from the mouth of Juan de Fuca Strait (see Fig. 1).

The community composition of phytoplankton, as derived from High-Performance Liquid Chromatography (HPLC) phytoplankton pigments, in the 2011 spring survey was similar to that observed in the spring of previous years (Fig. 3), despite the unusually high chl concentrations. Fucoxanthin, the biomarker for diatoms, was the most abundant accessory pigment in the Strait of Georgia at this time of the year, as expected during the spring bloom of diatoms. In contrast, the high phytoplankton biomass observed in the Strait of Georgia during the 2011 summer survey (June 21-25) was due to a bloom of the harmful raphidophyte flagellate *Heterosigma akashiwo*, as indicated by the accessory pigment data and corroborated by microscopic analysis. *Heterosigma akashiwo* has been one of the principal killers of farmed salmon in British Columbia (Taylor and Harrison, 2002). Blooms of this phytoplankton have been frequently observed in nearshore waters of the Strait of Georgia during the May through October period and Rensel et al. (2010) have postulated that they may adversely affect sockeye salmon through acute and chronic toxicity or food web impoverishment.

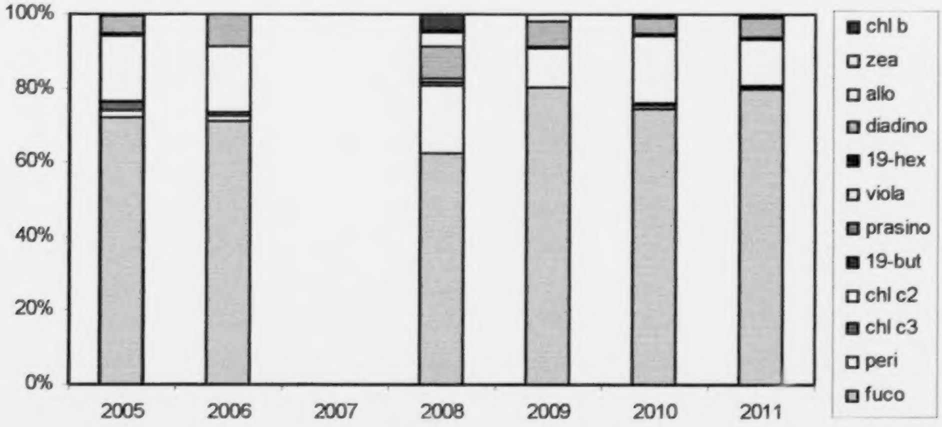

Figure 3. Time-series of relative contributions of phytoplankton accessory pigments in the upper layer at a station in the Strait of Georgia (see Fig. 1).

References

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2.3.4 Satellite observations of phytoplankton in the Strait of Georgia

Jim Gower[1] and Stephanie King[2]

[1]Fisheries and Oceans Canada
[2]SeeThis Consulting

2011: the most intense phytoplankton blooms observed by MERIS in the Strait of Georgia

The MERIS satellite measures ocean colour as it passes over the Strait of Georgia every day or so. From these colour measurements, scientists are able to identify the presence of ocean phytoplankton, and even estimate the relative biomass of this plant life at the ocean surface.

On June 22, 2012, a MERIS image showed extremely high values of the MCI index over large areas of the Strait of Georgia, especially near the Fraser River plume. The MCI (Maximum Chlorophyll Index) measures the spectral peak in water-leaving radiance at a wavelength of 709 nanometres, characteristic of intense, surface phytoplankton blooms. On this day the peaks dominated the spectra, indicating very high levels of chlorophyll in a near-surface bloom, but without the high infrared reflectance of floating vegetation or a more buoyant surface slick. *Heterosigma*, a species harmful to salmon, was identified in water samples collected by several observers in this and previous years when MCI signals were high. MERIS satellite imagery shows the time series of total MCI bloom signal since 2002 (Fig. 1).

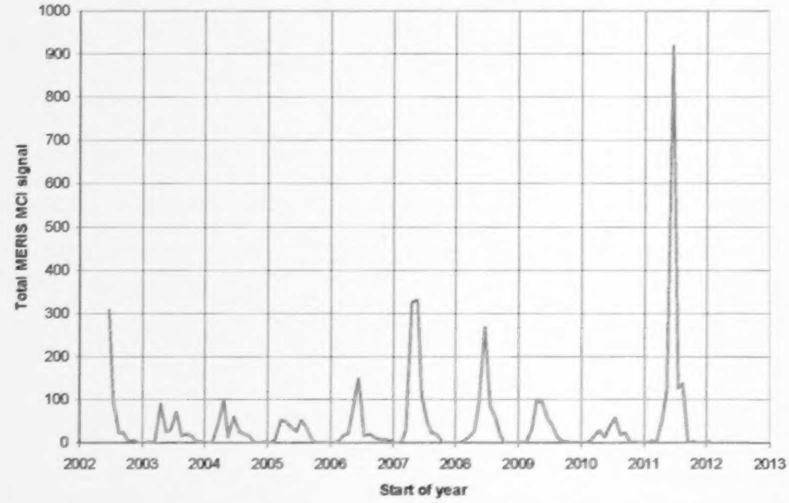

Figure 1. An intense surface bloom near the Fraser River plume and extending north-west up the Strait of Georgia, was imaged using the MCI (Maximum Chlorophyll Index) of MERIS in June 2011. The above time series of the total MCI signal in the Strait shows that the 2011 event was the strongest since MERIS observations began in 2002.

We cannot say that all high signals are *Heterosigma*, but this species probably represents a significant fraction. The total in June 2011 is about three times the total MCI signal of the previous maximum event in April/May of 2007. The bloom had died back by the end of June, but a second, less extensive event was imaged from July 4 to about July 30. The time series in Fig. 1 shows a strong peak in spring of most years. Omitting the 2011 data gives roughly equal signal from April to June, falling to half in July and with low levels in other months.

Fig. 2 below shows the Maximum Chlorophyll Index calculated from MERIS observations on 22 June 2011. The six small panels present the intensity of light at wavelengths between 400 and

900 nanometres, and the clear peaks in intensity at 709 nanometres, a signal specific to phytoplankton.

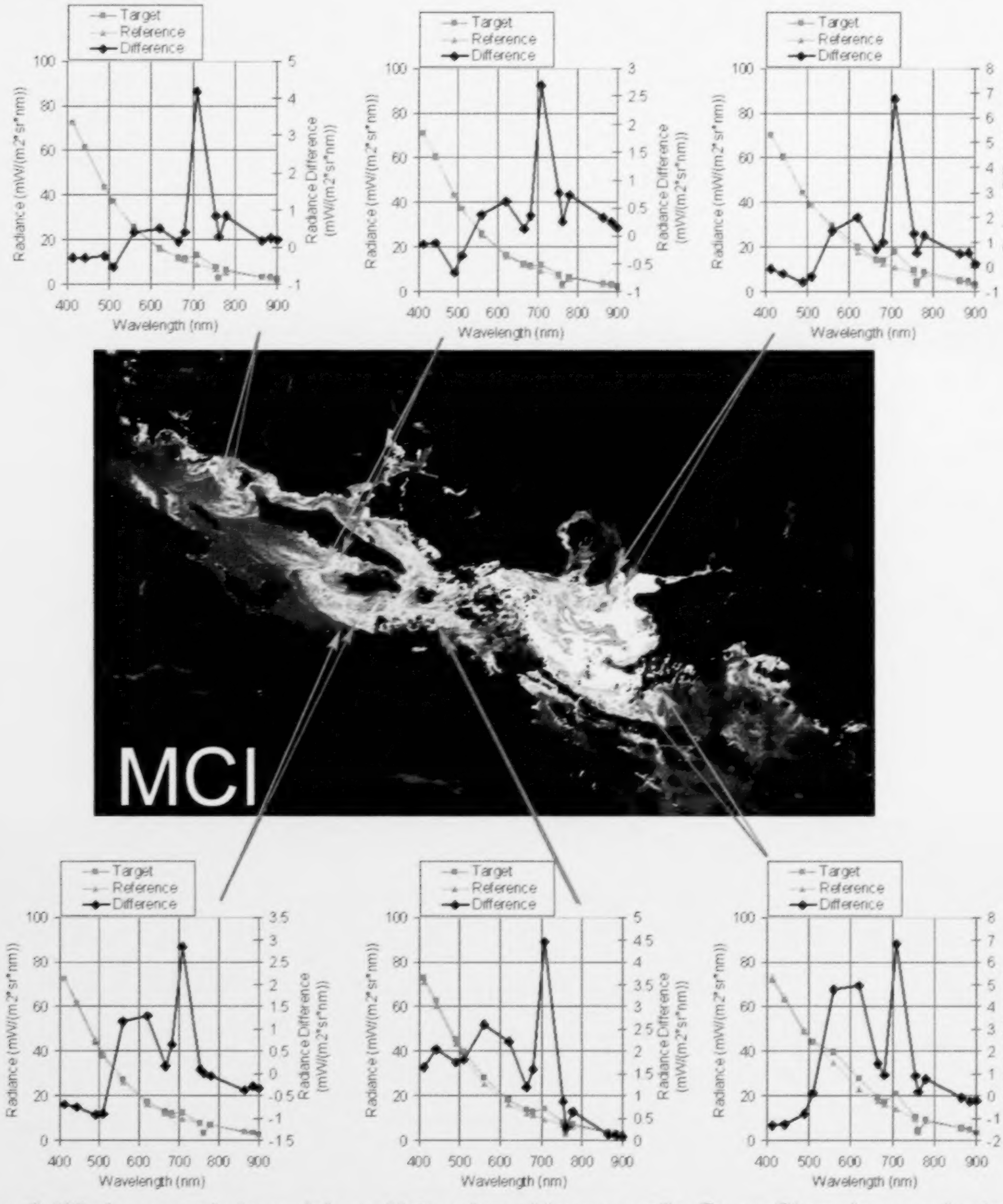

Figure 2. What appears to be an intense Heterosigma *bloom near the Fraser River plume and extending north-west up the Strait of Georgia, imaged using the MCI (Maximum Chlorophyll Index) of MERIS on 22 June 2011. Colours denote bloom intensity. Blue represents minimum, with intensity increasing as colours shift through green, yellow, red and white. Image shows high signal (white) off the mouth of the Fraser River. Difference spectra (blue in the six small panels) show the high radiance at 709 nm measured by MCI, indicating the presence of very intense ocean surface phytoplankton blooms.*

Strait of Georgia spring bloom timing

The start of the spring bloom marks the annual beginning of rapid phytoplankton growth in surface waters at northern latitudes. The bloom of phytoplankton is followed by a strong, but short-lived increase in zooplankton, which are important as a food source for juvenile salmon.

Different runs of salmon appear in the Strait of Georgia at different dates, which need to match zooplankton peaks for good survival of juvenile salmon. Timing of the bloom is therefore important. In 2011, satellite images and in-situ instruments showed a very late start to the spring bloom in the strait, on about April 6-8. This occurred about a week after a late bloom in Jervis Inlet was recorded at Egmont. This timing tends to confirm the previous observation that a late start to the spring boom in the Strait of Georgia is associated with a lack of early blooms in Jervis or Sechelt Inlets. Such early blooms in these inlets (nicknamed the Malaspina Dragon when they appeared in the Strait of Georgia) were observed to precede the much earlier spring blooms in 2004, 2005, 2007, 2008 and 2009. The graph in Fig. 3 shows years when no early spring blooms appeared in Jervis or Sechelt Inlets (labelled "without seeding") as distinct in timing from years when blooms in inlets did appear early in the year (labelled "with seeding").

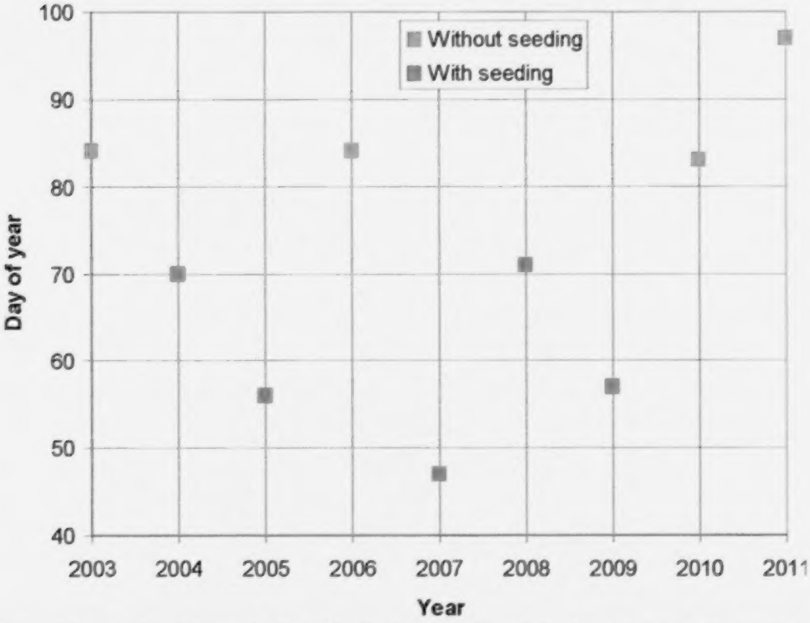

Figure 3. Start day of the spring bloom in the Strait of Georgia, plotted as day number of each year from 2003 to 2011. Green squares indicate years in which blooms occured in Jervis or Sechelt inlets, here interpreted as "seeding" the main spring bloom. Red squares show the later blooms (higher day numbers) in years without such blooms. Day 70 is March 11 on non-leap years.

We are now monitoring spring bloom timing with fluorometers on the Halibut Bank weather buoy off Sechelt in the Strait of Georgia, on a similar weather buoy in Saanich Inlet, on a boat dock at Egmont near the junction of Jervis and Sechelt Inlets, and on the BC ferry "*Spirit of Vancouver Island*" operating between Swartz Bay and Tsawwassen. There is no long-term funding to support these measurements, but the ferry time series should soon be taken over by VENUS (Victoria Experimental Network Under the Sea) with added routes across the strait from Tsawwassen and Horseshoe Bay to Nanaimo.

2.3.5 Spring phytoplankton bloom in the Strait of Georgia

Susan E. Allen and Douglas J. Latornell, Earth and Ocean Sciences, University of British Columbia

A phytoplankton bloom develops in late winter or early spring in the Strait of Georgia when rapid growth is triggered by sufficient light and nutrients in a shallow surface layer. This bloom starts to decrease when the near surface nutrients are consumed by the phytoplankton. The date of the maximum bloom (greatest phytoplankton biomass) is generally within a few days of when surface nutrients are exhausted. This date lags the start date of the bloom at ocean surface, as determined by satellite observations (Gower and King 2012, elsewhere in this report). The spring bloom of phytoplankton is dominated by diatoms, which are large phytoplankton that are important food for large zooplankton. Because large zooplankton provide feed for much of the food chain, timing and intensity of these blooms are believed to be critical for growth and survival of juveniles of many species.

The 2011 Spring Bloom

The date of maximum spring phytoplankton bloom in the Strait of Georgia is observed to vary interannually by six weeks (Collins et al, 2009). Using a computer model, the timing of the spring bloom has been hindcast from 1968 to 2010 by Allen and Wolfe (in press). Fig. 1 also includes the hindcast for 2011. No long-term trend is seen, but since 2007 we see later-than-average blooms (Fig. 1). The 2011 bloom continued this pattern, with the model hindcasting April 12 as the peak of the first bloom that brought surface nitrate to zero.

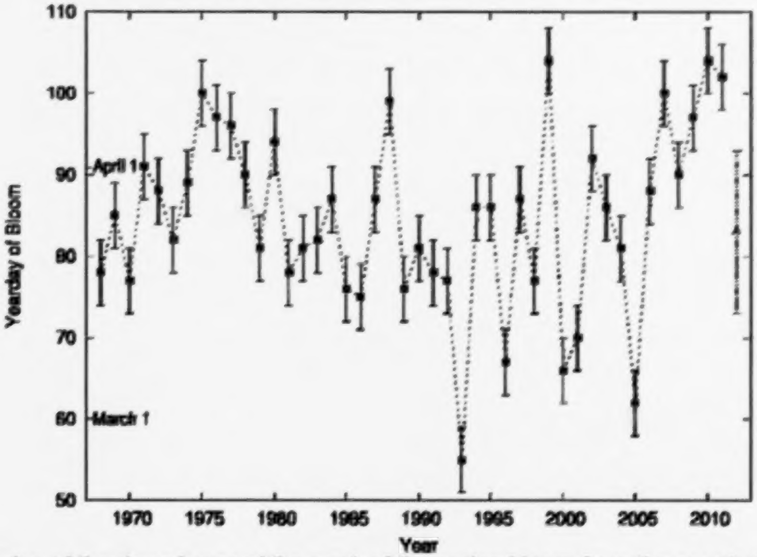

Figure 1: Time series of the day of year of the peak of the spring bloom from the coupled bio-physical model; adapted from Allen & Wolfe (in press), plus point for 2011. Also shown is the prediction for 2012 based on data to the end of February; this prediction date is too early because of March winds, see text.

The model results show low winter values of chlorophyll-a, with significant growth not beginning until mid-March 2011. Strong winds in the last week of March and first week in April pushed the peak of the bloom later than last year's forecast of March 16-April 5 (Allen et al, 2011). (Last year's forecast was provided in February 2011 and was not able to include the weather conditions of March 2011, whereas the hindcast dates for all years, which are computed after the bloom occurs, are able to include observations for March and April.)

Details of the coupled-biophysical model

The model is a vertical-mixing layer model forced by observed winds at Sand Heads, observed air temperature, humidity and cloud fraction at Vancouver International Airport (YVR), Fraser River flow at Hope and Englishman River flow at Parksville (Environment Canada, 2012a & b). The latter is multiplied by 55 to represent all river flows into the Strait other than the Fraser River. The physical model is based on the Large et al (1994) KPP-model with an estuarine circulation model added (Collins et al, 2009). To model a spring bloom, only a simple nitrate-diatom biological model is used. The diatom growth parameters are taken from the literature based on the first phytoplankton to bloom in the Strait (*Thalassiosira spp.*). The model zooplankton concentration was taken from observations (Sastri and Dower, 2009) and the model was tuned by adjusting the phytoplankton growth rate (Allen and Wolfe, in press) within the range measured in the laboratory. The model was tuned, within 4 days, for the spring blooms of 2002-2005, for which detailed observations were made as part of the STRATOGEM project (Allen and Wolfe, in press).

Prediction for bloom in 2012

An algorithm for the prediction of the timing of the spring bloom based on weather and rivers from December to February gives a prediction of March 13- April 3 for the spring bloom in 2012 (Collins et al, 2009). It successfully predicted the bloom timing in 2006, 2007, 2008 and 2009 (Allen and Wolfe, in press). This prediction implicitly assumes typical weather conditions for March. However, in the first 23 days of March 2012 we have seen several of strong wind storms; indeed, the average wind in March has been significantly higher than in any of the three preceding winter months. Thus, the spring bloom will be delayed beyond the Collins et al (2009) algorithm prediction. This weather pattern, of a stormy March following a benign winter, was also seen in 2010 when the algorithm predicted a much earlier bloom than observed.

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2.3.6 Zooplankton in the Strait of Georgia: a partial recovery from low copepod and euphausiid biomass levels in the 2000s

Dave Mackas, Moira Galbraith, and Kelly Young (Fisheries & Oceans Canada) and The Dower Lab (University of Victoria)

As part of the Pacific Region Ecosystem Research Initiative, we compiled historic data from various shorter term sampling programs in the Strait of Georgia (SoG) and have begun a retrospective analysis of long term changes in the SoG zooplankton community. Temporal coverage extends (with many gaps) back into the 1960s. Because of the diversity of sources and original project objectives, SoG zooplankton sampling did not follow a standard grid or sampling protocols, and in addition the data have highly variable resolution of taxonomic composition. For this reason, our analysis of the SoG zooplankton community has merged the source data into broader categories (size classes within major taxa) than the species level resolution used in our outer coast time series (Mackas et al. 2012, elsewhere in this research document).

In addition, many of the dominant zooplankton taxa in the Strait of Georgia make extensive vertical migrations at daily and/or seasonal time scales. For this reason, we have focused our analysis on the subset of samples that were collected at deep locations using net tows that sampled all or most of the water column (Fig. 1). From 1990-1995 and 1998-2010, sampling by DFO and the Universities of Victoria and British Columbia provided a methodologically-consistent and year-round set of time series samples that meet these criteria (unfortunately, there is at present no dedicated funding for an ongoing SoG zooplankton monitoring program, so we lack data from 2011).This report is a brief summary of an analysis of the 1990-2010 time series recently completed by Mackas, D.L., Galbraith, M.D., Faust, D., Masson, D., Romaine, S., Shaw, W., Trudel, M., Dower, J., Campbell, R., Sastri, A., El Sabaawi, R., unpublished manuscript.

An additional analysis by Li, L., Mackas, D., Hunt, B., Schweigert, J., Pakhomov, E., Perry, R.I., Galbraith, M., Pitcher, T.J.(unpublished manuscript) focused on a different subset of samples (1992-2007) collected by 0-50m net tows around the margins of the Strait.

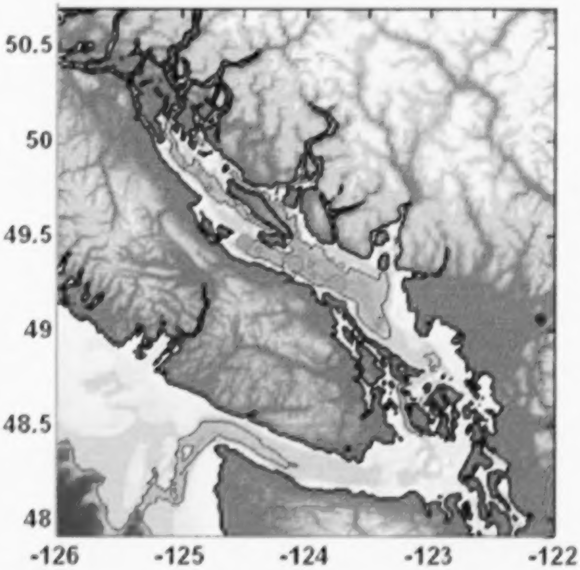

Figure 1. Zooplankton sampling locations (red circles) in the 1990-2010 Strait of Georgia zooplankton time series. Area of circle is proportional to the number of samples collected at each site. Bathymetry is indicated by blue shading. Black contour line is the 200 m isobath.

Both Li et al. and Mackas et al. report large decadal changes in the Strait of Georgia zooplankton community. The SoG zooplankton variability has been quite different in time scale and phasing from the outer coast time series described in Mackas et al. (2012, elsewhere in this research document): within the SoG we see little or no evidence of advectively driven oscillation between 'northern' and 'southern' communities, and somewhat more evidence of sustained trends and/or very low frequency fluctuations. Both in earlier years (Harrison et al. 1983) and since 1990 (Mackas, D.L., Galbraith, M.D., Faust, D., Masson, D., Romaine, S., Shaw, W., Trudel, M., Dower, J., Campbell, R., Sastri, A., El Sabaawi, R., unpublished manuscript), total zooplankton dry-weight biomass has been dominated by copepods (~40%, post -1990 time series in Fig. 2) and euphausiids (~29%, post-1990 time series in Fig. 3). In turn, the larger sized copepods were strongly dominated by the large copepod *Neocalanus plumchrus*. This species has an annual life cycle in the SoG (Fulton 1973) and completes its entire growing season between about January and May, after which it migrates downward to depths greater than 200m and enters a prolonged seasonal dormancy. Several recent studies (e.g. Bornhold 2000; Campbell et al. 2004; El Sabaawi et al. 2009) have documented large changes in its growing season (early in years with warm spring temperature), abundance, and chemical composition. Within the SoG, copepod biomass was lower after 2000 than in the early 1990s (Fig. 2) although there has been some recovery in 2009 and 2010.

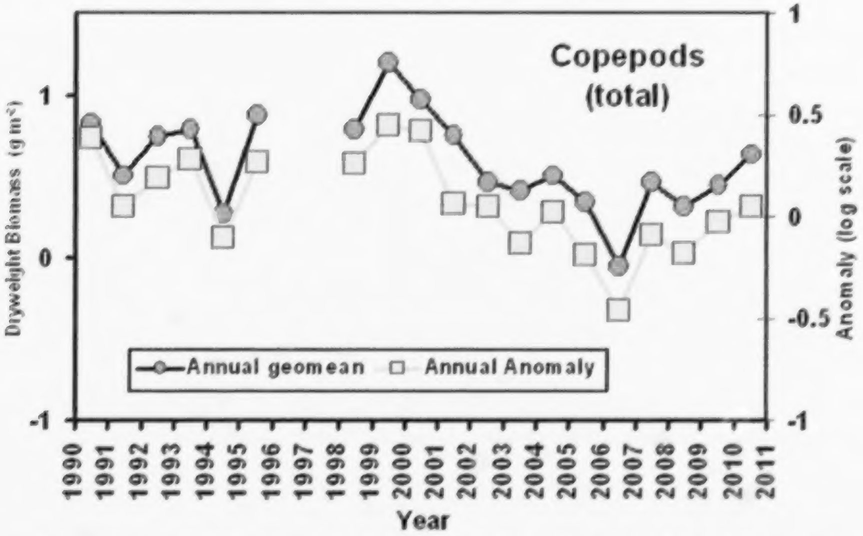

Figure 2. Annual geometric mean biomass and annual biomass anomalies of calanoid copepods in mid-strait full-water-column samples from the Central and Northern Strait of Georgia. Much of the large post-2000 decline (note that Y-axes scales are log10) is due to decreased abundance of Neocalanus plumchrus.

Euphausiid biomass was also very low in the mid-2000s (Fig. 3). Large copepods and euphausiids provide an energy-rich food resource for higher trophic levels (either direct or indirect through intermediate predators). High availability of these zooplankton taxa appears to enhance the growth and survival of juvenile salmon, herring and sablefish (Mackas et al. 2007; Trudel, pers. comm., Schweigert pers. comm.). Low SoG zooplankton biomass and changes in zooplankton community composition may have contributed to recent poor survivals and recruitments of certain salmon populations that forage in the Strait. However, the period of low biomass lasted several years, both before and during the 2007 ocean entry year for the Fraser River sockeye stocks that had very poor returns in 2009.

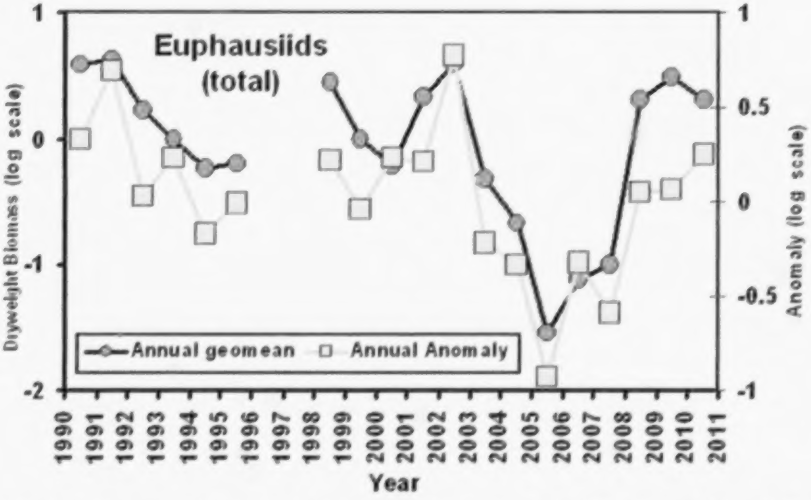

Figure 3. Annual geometric mean biomass and annual biomass anomalies of euphausiid in mid-strait full-water-column samples from the Strait of Georgia. Euphausiid data are adjusted for day-night differences in catchability before being averaged.

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2.3.7 Upper-trophic level changes in The Strait of Georgia ecosystem appear to be influenced by bottom-up-type mechanisms

Dave Preikshot and Ian Perry, Fisheries and Oceans Canada

Results from a model used to simulate changes in culturally and commercially important species in the Strait of Georgia ecosystem from 1960 to 2009 suggest that fisheries, predator-prey interactions, and marine production vary in their relative influence on different species. Furthermore, the relative influence of these mechanisms changes through different eras. Abundance changes for many upper tropic level species may have been driven, in part, by production changes, i.e., 'bottom-up' mechanisms. Simulated changes in primary production in this model are highly correlated with changes in summer wind speeds recorded at Vancouver International Airport, suggesting a possible link between this ecosystem and climate variation. Model results also demonstrate how Chinook salmon mortality from predators and fisheries has changed over time. Simulations suggest that, at present, predation mortality on adult Chinook salmon is likely far larger than fisheries mortality.

The EwE model hindcasts annual-average biomasses for species and groups by tuning predicted biomasses to reference time series from stock assessments (Christensen and Walters 2004). Tuning data were available for commercially and socially significant species like killer whales, harbour seals, marine birds, coho and chinook salmon, dogfish, lingcod, and Pacific herring. Top-down dynamics are modelled by parameterising the sensitivity of prey species mortality changes to changes in predator biomass. Bottom-up dynamics are simulated by hindcasting annual anomalies of primary production (Christensen and Walters 2004).

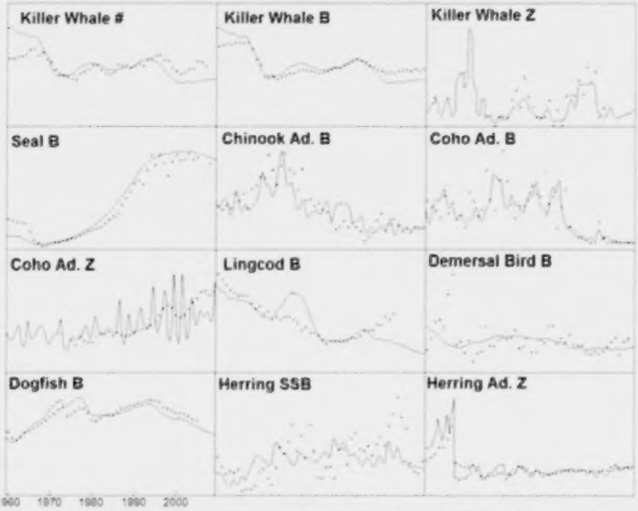

Figure 1. Hindcasts of model biomass (B) and total mortality (Z) for species with time series data. Model output is shown as line and reference data as points. Changes on the Y-axis are relative to the value in the first year of the simulation, i.e., 1960.

Fig. 1 shows that the model emulates the timing, direction, and magnitude of biomass changes in several important Strait of Georgia species. In our simulation, abundance changes in lingcod, killer whales, harbour seals and dogfish are mostly influenced by fisheries, a top-down mechanism. Other groups like coho salmon, Chinook salmon and herring also responded to bottom-up forcing. Results from this model, therefore, suggest how the ecosystem mediates recent increases in abundance of mammals like harbour seals and sea lions in the face of declining abundances of other predators like coho salmon, Chinook salmon, lingcod, and marine birds. The dynamics of killer whales and seals in this model are interesting in that removals and mortality in the 1960s (Carretta et al. 2011; Olesiuk 2010) dominates their dynamics during the early part of the simulation, but once the removals ceased in the 1970s, the abundance of killer whales and seals increased, and subsequent changes in abundance are also influenced by prey availability, a bottom-up mechanism.

The model shows that many of the commercially, socially, and biologically significant species in the model, are at or near historic low biomasses, e.g., chinook salmon, coho salmon, lingcod, killer whales and dogfish. While much of this decline is due to fishing, the model suggests that these low biomasses are better emulated when relatively low primary production starting in 1991 and continuing to 2012 was included in the simulation.

As mentioned above, the model fits seen in Fig. 1 were driven by an estimation of historic annual variation in phytoplankton production. These annual estimates of phytoplankton forcing show a high correlation to spring/summer wind speeds at Vancouver International Airport when lagged by two years, Fig. 2. The negative correlation suggests that years, or regimes, of relatively low spring/summer wind speeds are associated with years, or regimes, of relatively high primary production in the model. A period of increasing and/or relatively higher summer wind speeds appears to be coincidental with a period of relatively low primary production hindcast by the model. This relatively low primary production is manifested as biomass declines, after 1990, of coho and Chinook salmon, herring, dogfish, and killer whales.

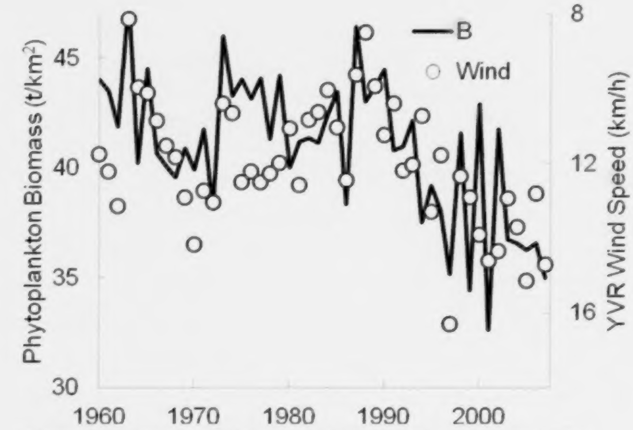

Figure 2. Relative changes of hindcast annual primary production anomalies, indicated by phytoplankton biomass (B), in the Strait of Georgia model versus mean spring/summer (March-September) wind speed at Vancouver International Airport (YVR), $R^2 = 0.43$. The wind-speed scale is inverted.

The capacity of the model to identify data gaps can be seen in how the model simulates killer whale biomass changes from 1960 to 2012. Initial runs with killer whales in this model were tuned to count data as that was, initially, the only abundance data available. When the model output is compared to southern resident killer whale counts (upper left hand box in Fig. 1), changes in abundance appeared to be poorly captured by the model. However, age structure data has recently become available for the southern resident killer whale population facilitating the construction of a biomass time series. When this time series was compared to the simulation of killer whale biomass in Fig. 1 (top row), the dynamics of the two are similar. Thus, the model suggests that biomass changes in killer whales are different than what might be suggested based on abundance data alone. This is particularly important given that the biomass decline associated with the removal of killer whales for the aquarium trade in the 1960s and 1970s appears to have never been replaced, although count data suggests the number of individuals at present is similar to the number in the 1960s.

This model has also proven useful in identifying trade-offs between predators and fisheries for fish resources in the Strait of Georgia. For example, there is some concern regarding the recovery of the southern resident killer whale population given their dependency on Chinook salmon (Ford and Ellis 2006). The Ecosim model was used to examine the relative effect that fisheries and predators (seals, sea lions, and killer whales) had on Chinook salmon, given different assumptions of predation by seals and sea lions. It is thought that seals and sea lions devote a relatively small proportion of their diet to salmon in general and adult Chinook salmon in particular (Olesiuk 1993). Although fisheries appear to have been a far larger source of adult Chinook salmon mortality prior to the 1990s, the model suggests that marine mammal predators likely now account for more adult Chinook salmon mortality than fisheries, Fig. 3.

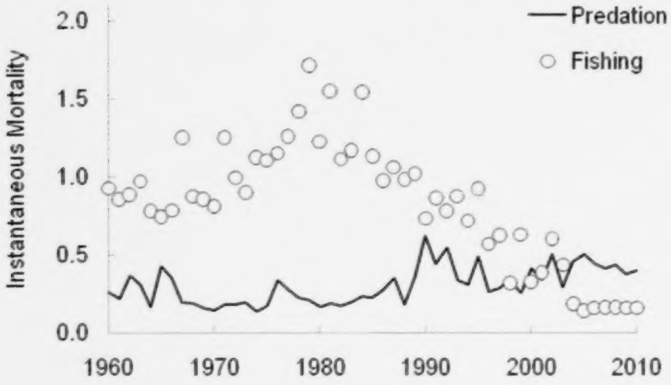

Figure 3. Relative simulated changes of hindcast adult Chinook salmon instantaneous mortality rates caused by marine mammals (line) and commercial and recreational fisheries combined (circles).

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2.3.8 Recent Fraser sockeye salmon returns and forecasts for 2012

Sue Grant, Fisheries and Oceans Canada

Fraser River Sockeye Salmon Life-History

Most Fraser Sockeye spend their first two winters (as eggs/alevins and, subsequently, as fry) in freshwater, followed by two or three winters in the ocean, returning to spawn predominantly as four and five year old fish. Given most Fraser Sockeye are four year old fish, many stocks exhibit four-year patterns of abundance. Late Shuswap, for example, has one dominant cycle (large returns on the 2006 return cycle line), followed by three weaker cycles (relatively small returns on the 2007-2009 cycle line). Harrison Sockeye (and a few other smaller populations) are the major exception to this life-history and age structure, spending only one winter in freshwater followed by two or three winters in the ocean, returning to spawn as three and four year old fish. Unlike most other Fraser Sockeye stocks, Harrison Sockeye four year old proportions can vary from 10% to 90% among years (Grant et al. 2010); therefore, this stock does not exhibit persistent four year patterns of abundance. For all Fraser Sockeye, mortality occurs throughout their life-history (eggs to returning adults) in both the freshwater and marine environment.

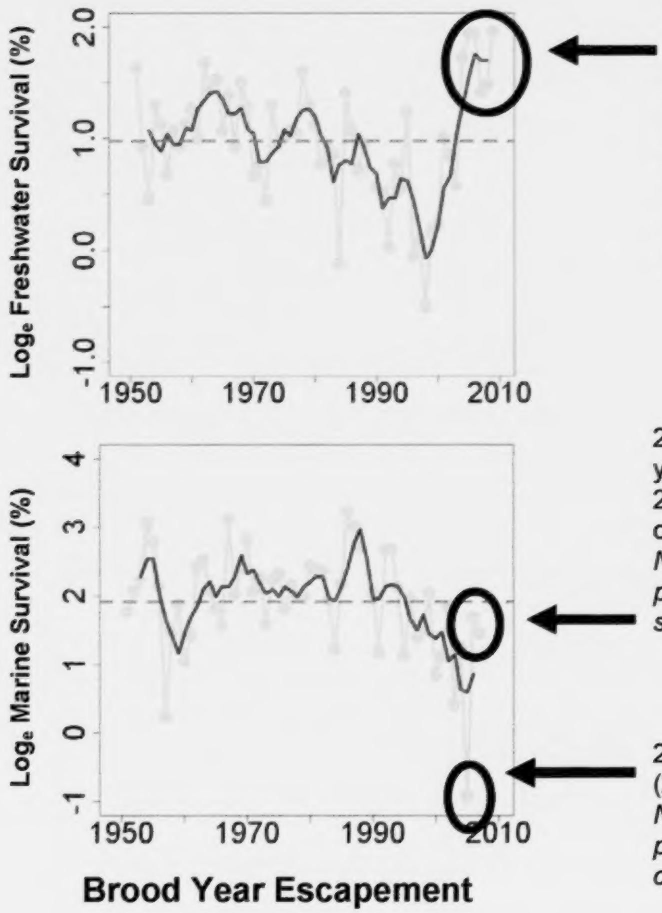
Return Forecast Uncertainty and Recent Survival

To decrease the high uncertainty associated with Fraser Sockeye return forecasts, environmental variables have been used both quantitatively in stock-recruitment forecast models (Grant et al. 2010) and qualitatively into the forecast advice (DFO 2009). However, to date, environmental variables have not decreased Fraser Sockeye forecast uncertainty significantly and the influence of environmental conditions on survival remains an area of active research (see Irvine et al. 2012 and Sweeting 2012, both elsewhere in this research document).

In the absence of leading survival indicators, Fraser Sockeye forecasts have been particularly uncertain in recent decades given the systematic declines in survival exhibited by most stocks (Grant et al. 2010 & 2011), which culminated in the lowest survival on record in the 2005 brood year (2009 four-year-old and 2010 five-year-old returns). The subsequent 2006 and 2007 brood year total survivals, based on their respective 2010 and 2011 preliminary returns, are closer to their long-term averages. The indicator stock for Fraser Sockeye, Chilko Sockeye, has similarly exhibited declines in total survival (Grant et al. 2010 & 2011), with improvements in very recent brood years (2006 & 2007). Given Chilko Sockeye have a long time series of smolt data, total survival can be partitioned into freshwater and marine. Recent trends in total Chilko survival coincide largely with changes in marine survival (Fig. 1).

Recent Returns in 2010 and 2011

Although survival has similarly improved in the 2006 and 2007 brood years, relative to the recent low survival period for most Fraser Sockeye stocks, associated returns (respectively, 2010 and 2011) have varied. Large differences in returns between 2010 (preliminary estimate: ~30 million) and 2011 (preliminary in-season estimate: ~5 million) are attributed primarily to differences in brood year escapements (adult spawners in the parental generation as an index of egg abundance), rather than large differences in survival (from the egg stage through to adult returns). For the 2010 returns, the 2006 adult brood year escapements were relatively high (~5 million), driven by Shuswap Lake stocks which exhibit high abundances on this dominant cycle (i.e. Early Summer timed Scotch and Seymour and Late Run timed Shuswap). In contrast, 2011 lower returns (relative to 2010) are attributed to the lower 2007 brood year escapements (~900,000) typical of this cycle, relative to the previous year.



2004 to 2009 brood years (respectively, 2006 to 2011 smolt outmigration years)
Note: 2011 smolt data are an in-season preliminary estimate only and are subject to change

2006 & 2007 brood years (respectively, 2010 & 2011 four year old returns)
Note: return data are preliminary and subject to change

2005 brood year (2009 four year old returns)
Note: 2009 return data are preliminary and subject to change

Figure 1. Chilko River Sockeye A. freshwater ($\log_e$ smolts per egg) and B. marine ($\log_e$ recruits per smolt) annual survival (light blue line) and smoothed four-year running average survival (dark blue line). Red dashed lines in both plots are long-term average survivals.

Future Returns

The 2012 total forecasted returns for Fraser Sockeye range from 743,000 to 6.6 million at the 10% to 90% probability distribution (MacDonald & Grant 2012,). Forecasts are presented as probability distributions to reflect inter-annual random (stochastic) variability in Fraser Sockeye survival, and, typical of salmon forecasts, uncertainty is large (Haeseker 2007 & 2008; Grant et al. 2010). Brood year escapements for the 2008 brood year (which will produce four year old returns in 2012), were below their cycle averages for 63% of the stocks forecasted. For some stocks, given the much lower four year old brood year escapements compared to five year olds, the proportion of four year olds (~75%) was lower than average (82%). The 2012 Fraser Sockeye forecasted returns fall largely (up to a three-in-four chance, based on past observations) below the cycle average (3.8 million). If Fraser Sockeye resume their low survival trends of recent decades, then 2012 returns have the potential to be amongst the lowest observed on this cycle. Conversely, there is a small (one in four) chance that returns could be above the cycle average, if stock productivities fall at the high end of past observations. Return abundances are not expected to improve in 2013, as these returns come primarily from the 2009 very low brood year escapements. The next year with a high probability of improved returns is 2014, resulting from high escapements in 2010 in most systems, particularly Late Shuswap.

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2.3.9 Survival patterns of Fraser River sockeye and pink salmon

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Evaluating relationships between marine indicators and salmon survival is most likely to be fruitful when the errors associated with survival time series are well understood. Here we examine survival time series for Chilko Lake (central Fraser River watershed) sockeye salmon and Fraser River pink salmon.

Sockeye Survival

At Chilko Lake, emigrating smolts are enumerated as well as returning adults (see Grant et al. 2012, elsewhere in this research document). This enables one to partition mortality into two major life history phases: egg to smolt (freshwater); and smolt to adult (mostly marine). Most Chilko Lake smolts leave the lake after one year (post fry/alevin) but ~4% leave after a second year and these have been counted, but in most studies, these data were ignored. We are investigating the possibility that two-year-old smolts provide additional information about Chilko sockeye survival in response to environmental effects.

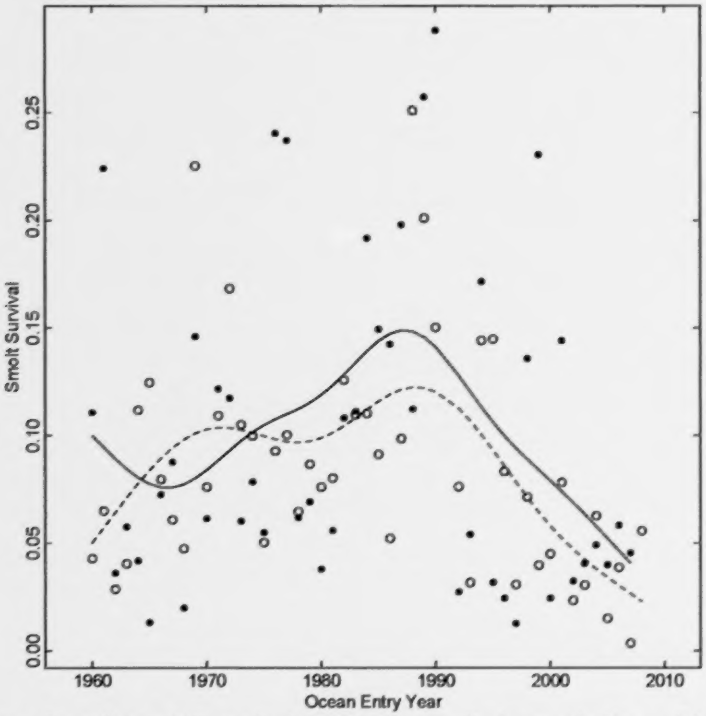

Figure 1. Time series of smolt-to-adult survivals for 1-year smolts (open circles and dashed line) and 2-year smolts (solid circles and line) from Chilko Lake. Some estimates for 2-year smolts are unreliable because they were a small fraction of the sample taken for aging, particularly 1964, 1980, 1992, and 2007. Lines created with generalised additive regression (mgcv package in the computing language R).

When organized by ocean entry year, the smolt survival time series for the two age classes are similar, with each exhibiting large interannual variability (Fig. 1). After correcting for non-normal distributions, the trend line and mean survival (0.072 or 7.2%) for each age group are the same. We are exploring various analytical approaches to see whether our understanding of post-smolt survivals can be improved with these two data sets. In one approach, we used principal components of the age ratios in smolts and returns to identify cases with high binomial sampling error for survival of 2-year smolts. After down-weighting those cases, we merged the two survival time series (Fig. 2). The noise in survival estimates has been eliminated sufficiently to reveal a sharp pattern break in 1990, where the trend in survival changed from increasing to decreasing.

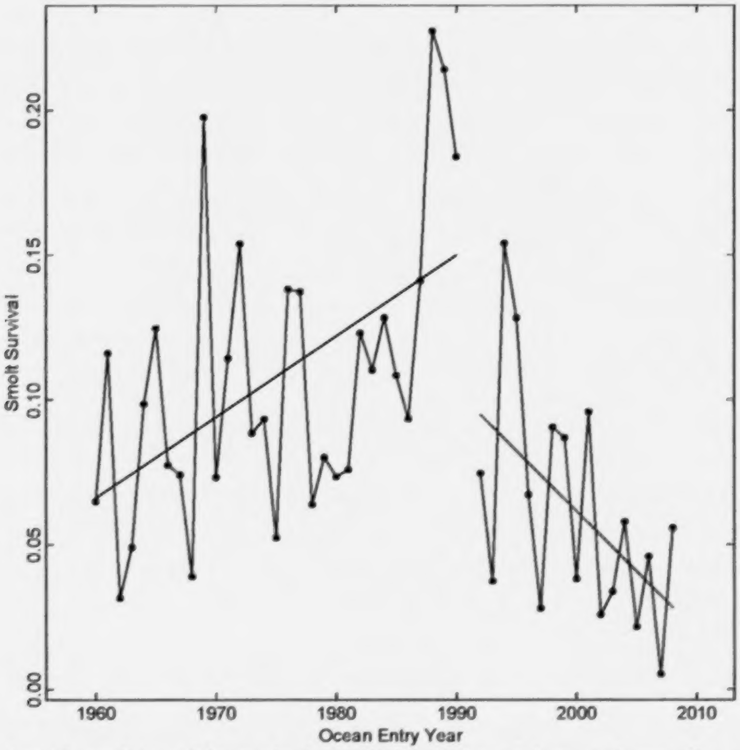

Figure 2. Time series of smolt-to-adult survivals for Chilko Lake sockeye salmon after merging survivals of 1-year smolts with 2-year smolts after the latter were downweighted in years with high sampling variance.

Pink Salmon Survival

Pink salmon have a very different life history than sockeye salmon, living for only 2 years, and in the Fraser almost all return in odd numbered years. Approaches to estimate escapements have varied over time and although efforts have been made to standardize the time series, issues about data quality remain. Nevertheless, time series of catches and escapements, as well as fry production indices allow us to develop time series of marine and freshwater survival indices, escapements and fishery exploitations (Fig. 3).

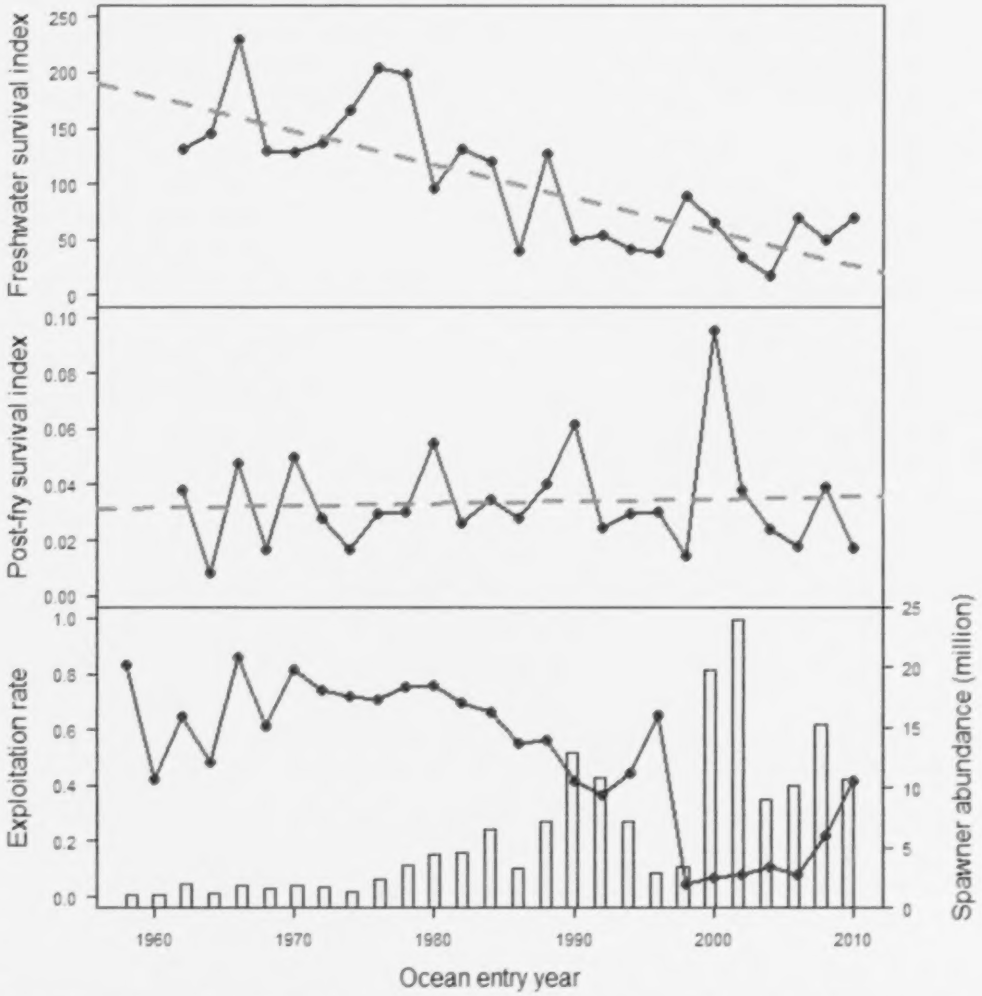

Figure 3. Freshwater and post-fry (marine) survival indices and spawner abundance (histogram) and fishery exploitation rates for Fraser River pink salmon

Marine survivals are without trend, while freshwater survival indices declined during the time series. A generally increasing pattern of increasing escapements is only understood by recognizing declining fishery exploitations during the time period (Fig. 3).

Summary

Fraser sockeye (Chilko) post smolt survivals generally increased from 1960-1989, and declined since. Recent escapement increases for Fraser pink salmon occurred in response to reduced exploitation, despite stationary marine survivals and declining freshwater survivals. Future work will examine relationships between these survival time series and various environmental indicators.

2.3.10 The state of salmon in the Strait of Georgia

R.M. Sweeting, Fisheries & Oceans Canada

Surface water temperatures (SSTs) in the Strait of Georgia were slightly cooler in 2011, particularly in the peak June-August period where the average SST was ~16.6 °C (Fig. 1A; Chandler 2012, elsewhere in this research document). Two of the previous three years saw average SSTs of over 17°C during this critical stage in the early marine phase of juvenile Pacific salmon. Peak flows of the Fraser River freshet in April (Fig. 2A and B) also continued to be lower than the decadal average and much lower than rates observed in the 1990s. Based on our observations, the values of these two indicators suggest that productivity conditions in the Strait of Georgia in 2011 should have been good. However, sea surface salinities in the Strait of Georgia in the winter months (i.e. November thru February, 2010-2011) (Fig. 1B) averaged significantly higher than the previous 12 years, which may have had some impact on productivity.

Surveys for juvenile salmon have been conducted in the summer (June/July) and fall (September) in the Strait of Georgia since 1998. Tracklines and methods are as in Beamish *et al.* (2010). Data from these midwater trawl surveys are used as proxies to forecast marine survival trends for that brood year. As different species of Pacific salmon spend different numbers of year at sea, the forecast values from these ocean entry year surveys impact different return years.

For coho salmon, a very large catch per unit effort (CPUE) of juvenile salmon in the July 2010 survey suggested a high early marine survival and strong adult returns for 2011. Returns of these coho salmon as adults to the Strait of Georgia in 2011 were not, however, strong and were lower than all forecast models (DFO, 2012). For the summer 2011 survey, the CPUE value was approximately one-half (32.5) the long-term average (67.2), and adult coho salmon returns to the Strait of Georgia in 2012 are thus projected to be poor. This low expectation was also mirrored in data from the September survey in 2011. Data from the fall surveys are also being developed into a forecasting tool (Beamish et al., 2010)

Chinook salmon, on the other hand, may spend from 3-5 or more years at sea before returning to spawn in the freshwater rivers and streams feeding into the Strait of Georgia. For 2012, a low CPUE of juvenile salmon in the July 2009 survey indicated a continuation of the current low level of marine survival for this species. A low July Chinook CPUE was also observed in both 2010 and 2011 and thus, returns of adult Chinook to the region in 2013 and 2014 are projected to be poor.

Chum salmon spend 3 years at sea before returning to spawn in freshwater. Adult chum returns to the Strait of Georgia in 2012 should be exceptional, based on the extremely high CPUE of juvenile salmon observed in the July 2009 survey. The very low CPUE from the July 2011 survey suggests that early marine survival was poor, and poor returns are expected in 2014.

Pink salmon spend one year at sea before returning to spawn. The Fraser River population spawn only in odd years, and large populations of juvenile pink are found in the Strait of Georgia only in the following even years. In the summer survey of 2010, the CPUE for juvenile pink salmon was some 7-fold higher than any previous value, indicating an exceptional early marine survival rate for this brood year. Thus, very good adult pink returns were forecast for the Strait of Georgia in 2011. The actual return of adult pink salmon to the Fraser River in 2011 (currently 20M) was in line with our forecast. Juvenile pink abundances in the Strait of Georgia in 2012 may again be very high, leading to interactions with other juvenile salmonids and other pelagic fishes.

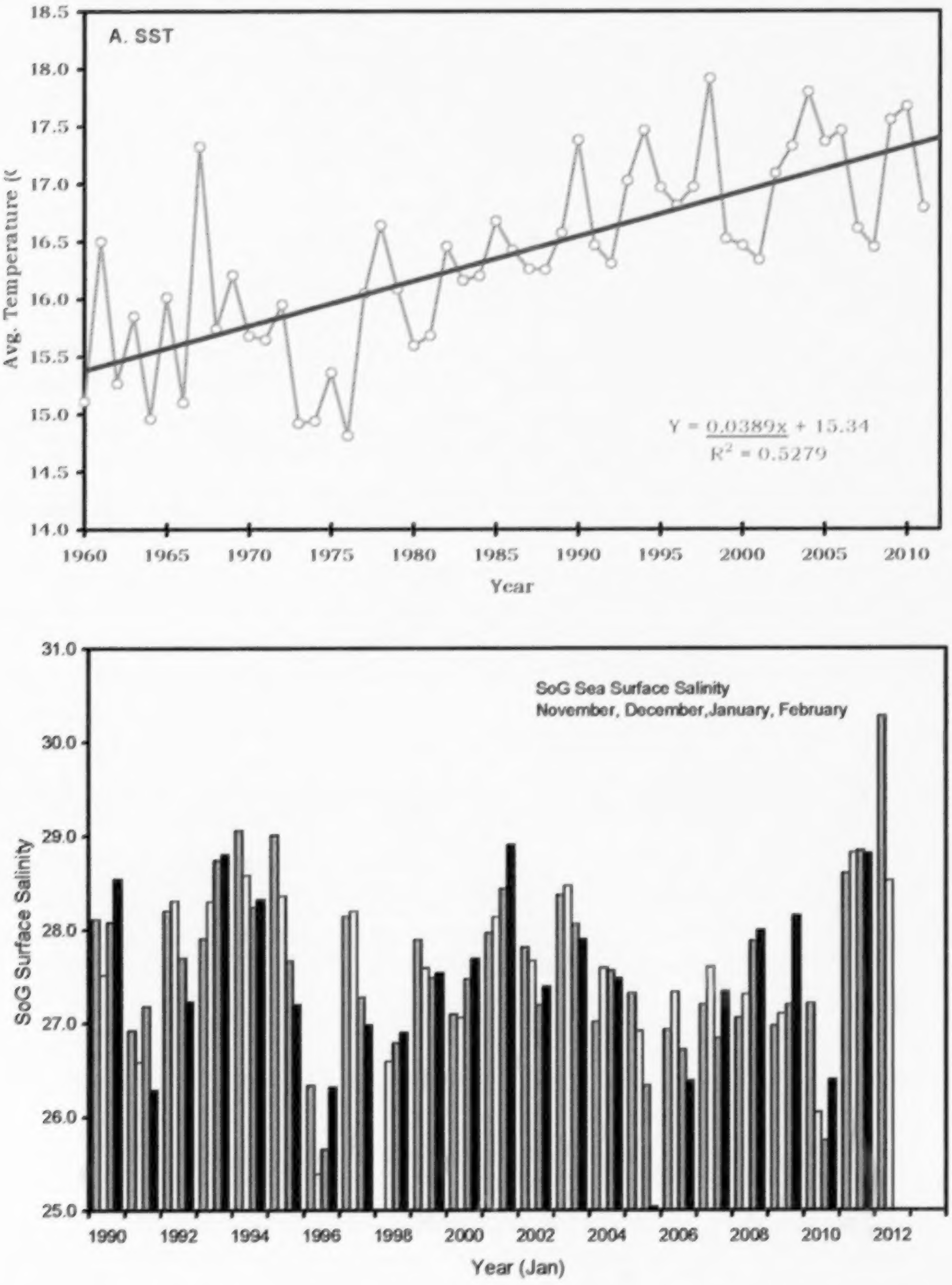

Figure 1. (top). Sea surface temperatures (SST) for the summer months (June-August) in the Strait of Georgia. (bottom) Sea surface salinities (SSS) for winter months (November thru February) in the Strait of Georgia.

Sockeye salmon trends have received intense scrutiny in the past few years. Most sockeye salmon spend 2 years at sea before returning to spawn. Fraser River sockeye are characterized by four distinct four-year cycles: the dominant Adams River cycle (high abundance), a sub-dominant cycle (medium abundance) and two off cycles (low abundance). Sockeye returns to the Fraser River are forecast to be poor in 2012 and 2013, due to the low, off-cycle populations. Our low CPUEs of juvenile sockeye salmon suggest that this trend will not change.

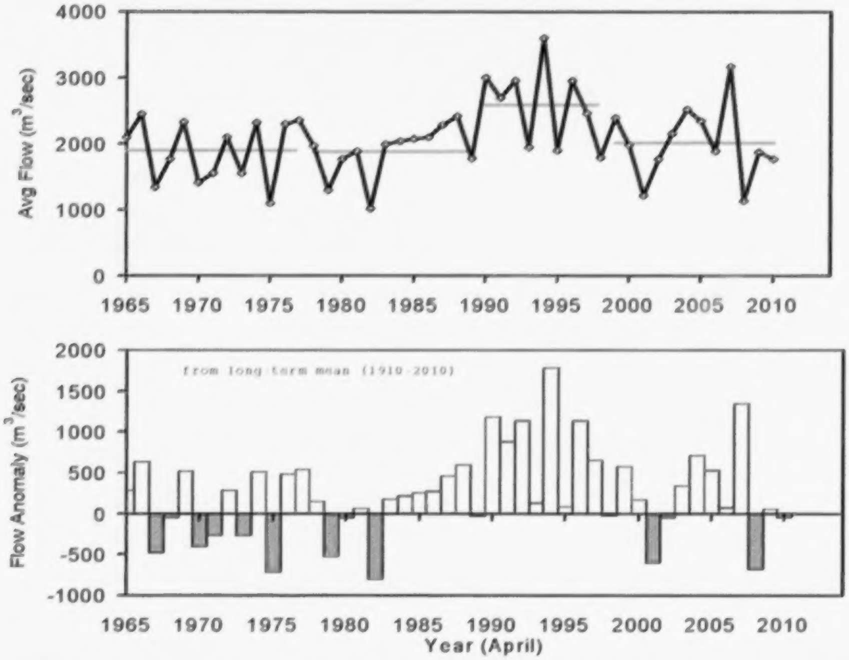

Figure 2. Discharge (cubic meters per second) for the Fraser River at Hope for (top panel) April 1965-2011 and (bottom panel) anomaly from long-term (1910-2010) average April flow rates. Data are from station # 08MF005, provided by Water Resources Branch, Environment Canada.

Recent genetic research into juvenile salmon population structure in the Strait of Georgia has identified that both the Chinook and sockeye salmon populations are quite different between the two seasonal surveys. In the July surveys, the populations of both species are composed of numerous, well-mixed populations or stocks from throughout the region. However, by September, the Chinook population has been almost entirely replaced by Chinook of South Thompson origin. In the case of sockeye salmon, the multiple stocks present in the summer months have been replaced by the Harrison River population. Both of these late-entry populations are 'ocean-type' life history strategists: they move into the marine environment after only a short time in freshwater and spend several months in the near-shore areas before moving into the open waters of the Strait of Georgia in the late summer.

While recent marine survival rates of Harrison River sockeye have generally been higher than other Fraser River stocks, CPUE data from the September 2010 survey suggests that adult returns to the region in 2012 will be very poor. Furthermore, there appears to be a negative interaction with juvenile pink salmon abundance and juvenile Harrison River sockeye salmon, and there was an extremely high pink salmon abundance in 2010. However, there are also some indications that the 2012 return may be composed of a large number of 4 year olds (i.e., spend 3 years at sea), again correlated with high juvenile pink abundances in 2010 (manuscript in prep). Returns of Harrison sockeye salmon in 2011 should have been good, based on a strong CPUE value in the September 2009 survey. Returns of Harrison Lake sockeye to the system in 2011 were projected to be 1.1 million (http://www.psc.org/NewsRel/2011/NewsRelease10.pdf), substantially greater than the highest previous value.

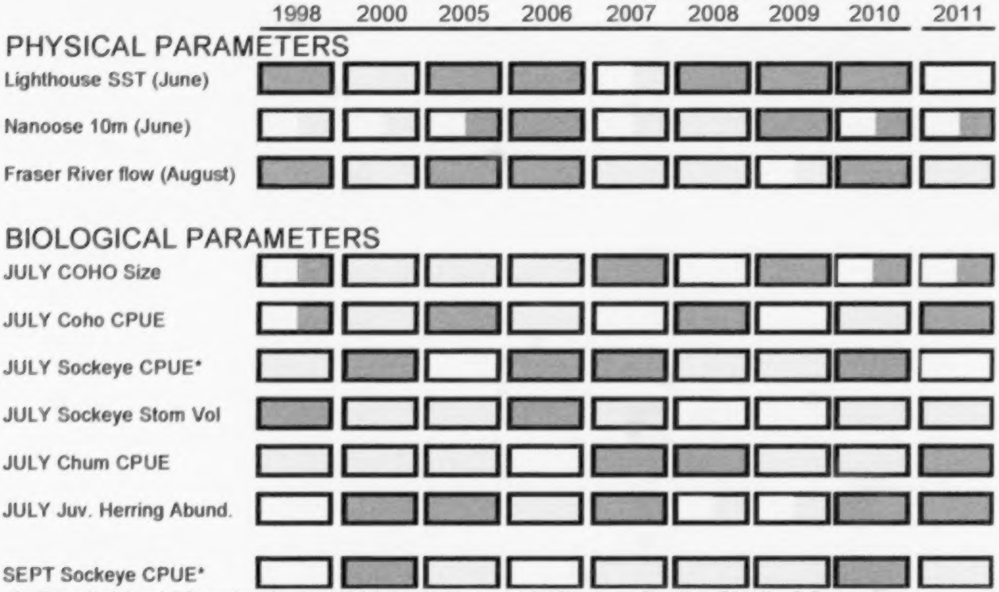

Figure 3. Stoplight grid for physical and biological proxy indicators for the Strait of Georgia.

For South Thompson Chinook salmon, the forecast from the September surveys is for a continuing increasing trend in marine survival and adult returns, based on four consecutive years of above-average September CPUEs.

It is interesting that these two late-entry stocks have exhibited higher average marine survival and return rates than the early-entry stocks of both species. They apparently move into the open waters of the Strait of Georgia at a time of highest surface water temperatures and yet are exhibiting higher returns. We are currently preparing a manuscript exploring this concept.

Using the stoplight system, Fig. 3 shows the general pattern of some proxy indicators in the Strait of Georgia. While some proxies are green (e.g., sockeye), most are yellow or red, indicating that the ecosystem as a whole continues to be in a state of concern.

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2.3.11 Telemetry-based estimates of early marine survival of Fraser and Columbia River salmon, 2011

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Introduction

We used a large-scale acoustic telemetry array to estimate early marine survival and movements of juvenile Pacific salmon as they migrated from large rivers into the coastal ocean. Salmon smolts were surgically implanted before release with a uniquely coded acoustic transmitter ("tag") and then tracked with a network of individual acoustic sensors positioned within the Columbia and Fraser rivers, and the continental shelf between central Oregon and the northwest coast of Vancouver Island, including the Salish Sea (Fig. 1). By reconstructing the movements of each individual salmon from the data recorded by the array, it was possible to estimate survival using the Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965). This report focuses on components of the array that were designed and deployed by Kintama, as well as components of the array managed by the Pacific Ocean Shelf Tracking (POST) project and the Ocean Telemetry Network (OTN).

In 2011, we estimated survival of Chilko Lake sockeye salmon from Chilko Lake, BC, to the mouth of the Fraser River, and from the river mouth through the Strait of Georgia (SoG) and Johnstone Strait/Discovery Passage to Queen Charlotte Strait, NE Vancouver Island.

We also estimated survival of yearling spring Chinook salmon in the lower 220 km of the Columbia River and estuary, and from the mouth of the Columbia River along the continental shelf off Washington State to Lippy Point, Vancouver Island. This second data set provided a comparative time series of survival values for the "outer coast" region off the west coast of Washington State and Vancouver Island. We also compared the telemetry-based early marine survival estimates for Chinook to independent oceanographic measurements of ocean conditions reported by NOAA and DFO.

2011 was the sixth year for which we have estimated early marine survival of Columbia River basin spring Chinook (see Porter et al. 2011), and the second year for which we have estimated survival of Chilko Lake sockeye smolts. However, in 2004-07, we made similar measurements for young Cultus Lake sockeye salmon migrating down the Fraser River and out of the SoG, including the crucial 2007 smolt outmigration year which led to extremely low returns in 2009 (see Welch et al. 2009). Thus, we now have six years of direct, telemetry-based survival measurements for Chinook and sockeye smolts along the outer coast of Vancouver Island and for the Salish Sea/Queen Charlotte Strait regions.

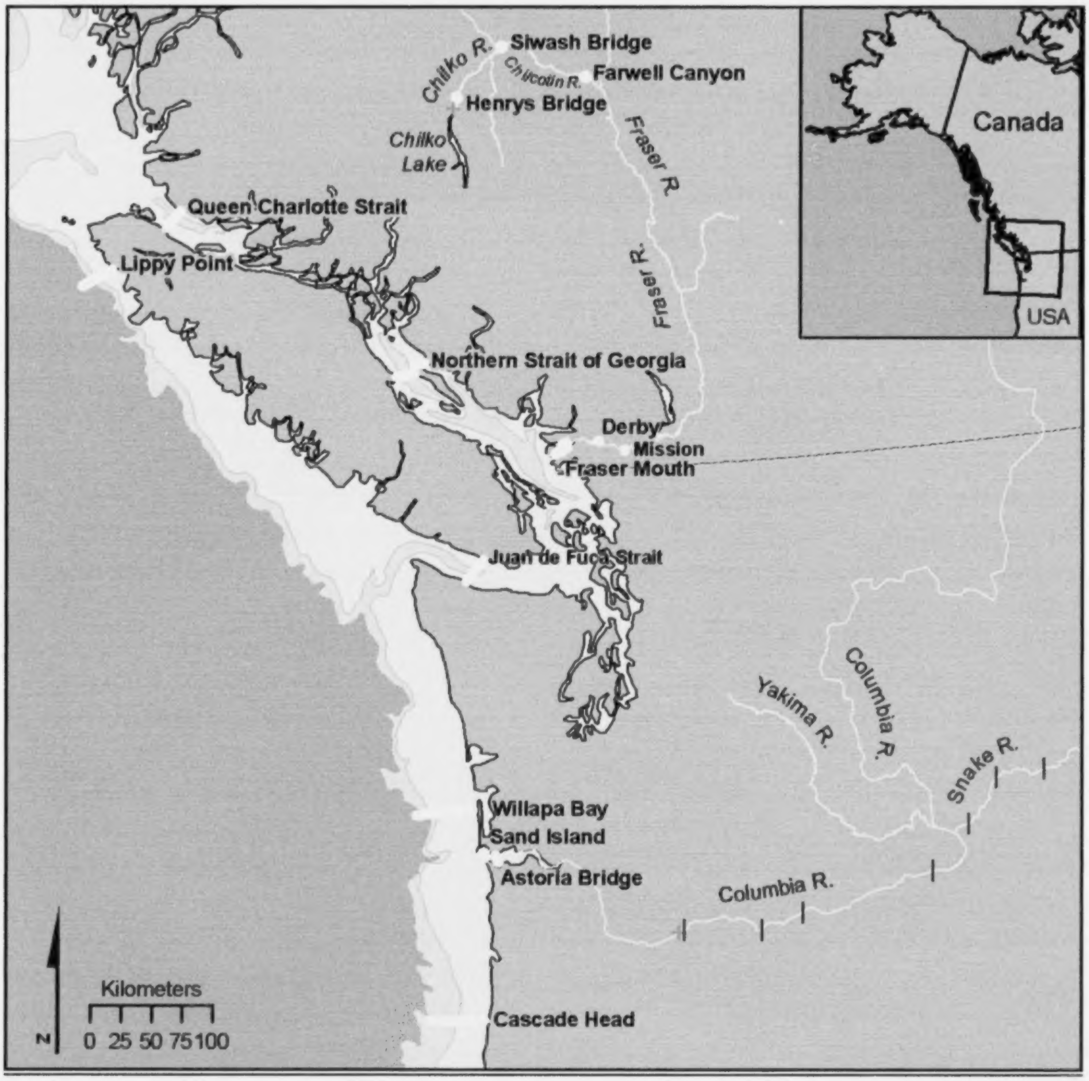
Siwash Bridge
Chilko R.
Chilcotin R.
Farwell Canyon
Henrys Bridge
Chilko Lake
Fraser R.
Queen Charlotte Strait
Lippy Point
Fraser R.
Northern Strait of Georgia
Derby
Mission
Fraser Mouth
Juan de Fuca Strait
Columbia R.
Yakima R.
Snake R.
Willapa Bay
Sand Island
Astoria Bridge
Columbia R.
Kilometers
0 25 50 75 100
N
Cascade Head
Canada
USA

Figure 1. Map of the acoustic receiver array (yellow lines and dots) used to track juvenile Columbia River Chinook salmon and Chilko Lake (Fraser River) sockeye salmon. Red crosses represent release sites. Isobaths (200 and 500 meter) are coloured in pale blue. Vertical black lines represent hydro dams. The Salish Sea includes Puget Sound to the south, Johnstone Strait to the north and Juan de Fuca Strait to the west.

2.3.11.1 Chilko Lake sockeye early marine survival

In 2010 (n=199) and 2011 (n=254) we tagged and released two-year-old, wild, Chilko Lake sockeye smolts at the DFO Chilko Lake counting fence near the outlet of Chilko Lake. Estimated survival from this release point to the Fraser River mouth was 21% (standard error (SE)=4%) in 2010, and 31% (SE=4%) in 2011. Survival through the Strait of Georgia was 76% (SE=24%) in 2010 and 38% (SE=10%) in 2011. Subsequent survival through Johnstone Strait/Discovery Passage to Queen Charlotte Strait was only 17% (SE=9%) in 2010, and 61% (SE=18%) in 2011. Cumulative survival from the release point at Chilko Lake to Queen Charlotte Strait was 3% (SE=2%) in 2010 and 7% (SE=2%) in 2011 (Fig. 2). No smolts were detected migrating through Juan de Fuca Strait in 2010. In 2011, three smolts were detected on the Juan de Fuca Strait sub-array; two of these three fish were later detected on the Lippy Point sub-array.

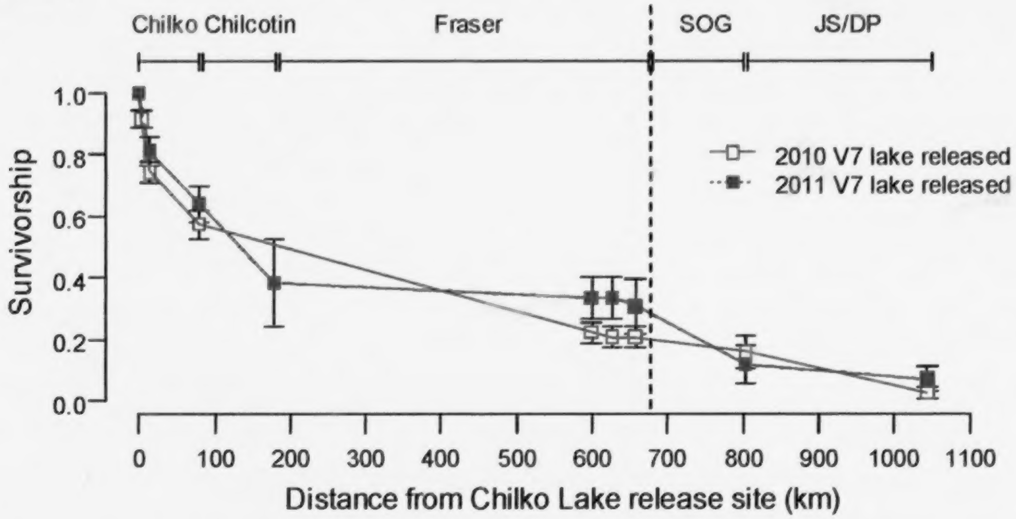

Figure 2. Cumulative survival of two-year-old Chilko Lake sockeye smolts from release at the DFO counting fence near the outlet of Chilko Lake to Queen Charlotte Strait (QCS; NE Vancouver Island). SOG-Strait of Georgia, JS/DP= Johnstone Strait/Discovery Passage, V7=VEMCO V7 transmitter (tag). Survival to QCS assumes a detection probability of 0.67 for the QCS sub-array. The dashed vertical line represents the Fraser River mouth. Error bars are 95% confidence intervals.

Wild Chilko sockeye smolts had relatively high and stable survival rates per week of travel time in the SoG in both 2010 and 2011, consistent with survival rates measured for hatchery-reared Cultus Lake sockeye in prior years (Fig. 3). Subsequent survival rate of these Chilko smolts through Johnstone Strait, Discovery Passage, and Queen Charlotte Strait was low in 2010 relative to their survival rate observed in the SoG. However, in 2011 survival rate per week of travel was substantially higher and similar to the survival rate observed in the SoG, and was also more consistent with earlier survival estimates using Cultus Lake sockeye (Fig. 3).

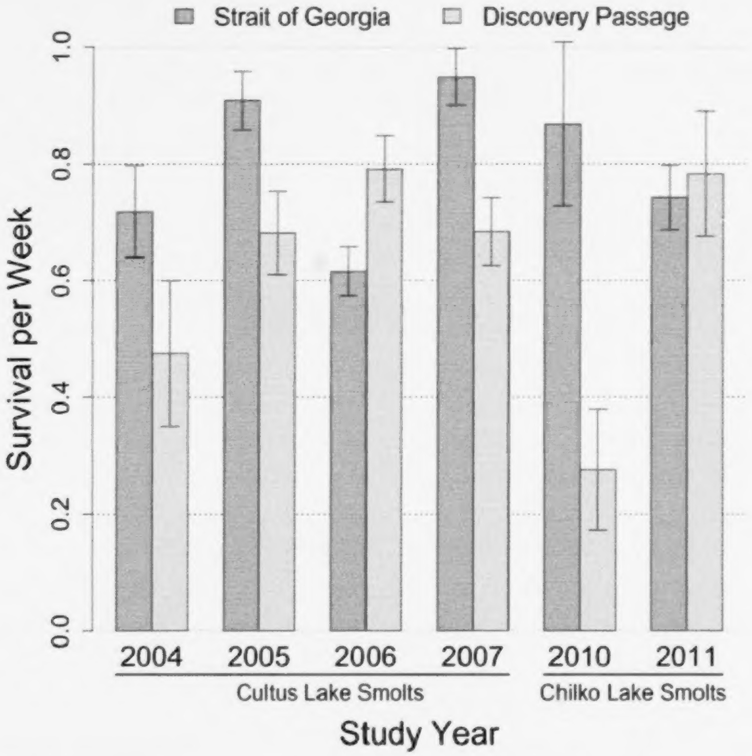

Figure 3. Survival rate per week for two-year-old Cultus and Chilko Lake sockeye smolts in the Strait of Georgia and Discovery Passage/Queen Charlotte Strait. Error bars show standard error.

Columbia River spring Chinook early marine survival

In 2011, yearling Chinook smolts ≥130 mm fork length were collected, tagged, and released at Bonneville Dam (n=580), or collected and tagged at Lower Granite Dam in the Snake River (n=200) and then transported downstream for release below Bonneville Dam. Stock of origin for each tagged individual was determined by genetic stock identification post-release. Thus, survival was estimated separately for in-river migrating mid/upper Columbia River spring Chinook (IRCol) and Snake River spring Chinook smolts (IRSnake) captured at Bonneville Dam, as well as Snake River spring Chinook smolts captured and transported (TRSnake) from Lower Granite Dam.

Nearly all smolts migrated north upon ocean entry (only six of 780 tagged smolts were detected south of the river mouth at Cascade Head). Our estimate of coastal survival of these smolts therefore reflects survival along the west coast of Washington and Vancouver Island, with BC waters forming about 2/3rds of the migration path. Estimated survival in the lower Columbia River and estuary was high and similar for all groups (IRCol: 84%, SE=4%; IRSnake: 81%, SE=4%; TRSnake: 78%, SE=5%). Plume survival (river mouth to Willapa Bay, ~50 km distant) was much lower (IRCol: 27%, SE=4%; IRSnake: 23%, SE=5%; TRSnake: 14%, SE=4%). Estimated coastal marine survival from Willapa Bay to Lippy Point (485 km) was 38% (SE=8%) for IRCol, 34% (SE=13%) for IRSnake, and 14% (SE=10%) for TRSnake.

Comparison of ocean ecosystem indicators and early marine survival estimates

Ocean ecosystem indicators (atmospheric, physical and biological) are collected, compiled, and ranked by NOAA (Peterson 2012, elsewhere in this research document) and, more recently, DFO (e.g. Trudel et al. 2012, elsewhere in this research document) in order to forecast marine survival of Pacific salmon along the open shelf of the west coast of Washington and southern British Columbia. Here we correlate early marine survival of Columbia River yearling Chinook salmon with ocean indicators provided by NOAA (Jacobson et al. 2012). Jacobson et al. (2012) show a strong correlation between ocean indicators for the Washington Coast and the west coast of Vancouver Island.

The intermediate levels of early marine survival observed in 2011 are consistent with NOAA's survival forecast for 2011 based on atmospheric, physical and biological ecosystem indicators (Fig. 4). Overall, our spring Chinook survival estimates using the POST array continue to track survival forecasts based on environmental variables and also demonstrate that very large between-year changes in survival occur.

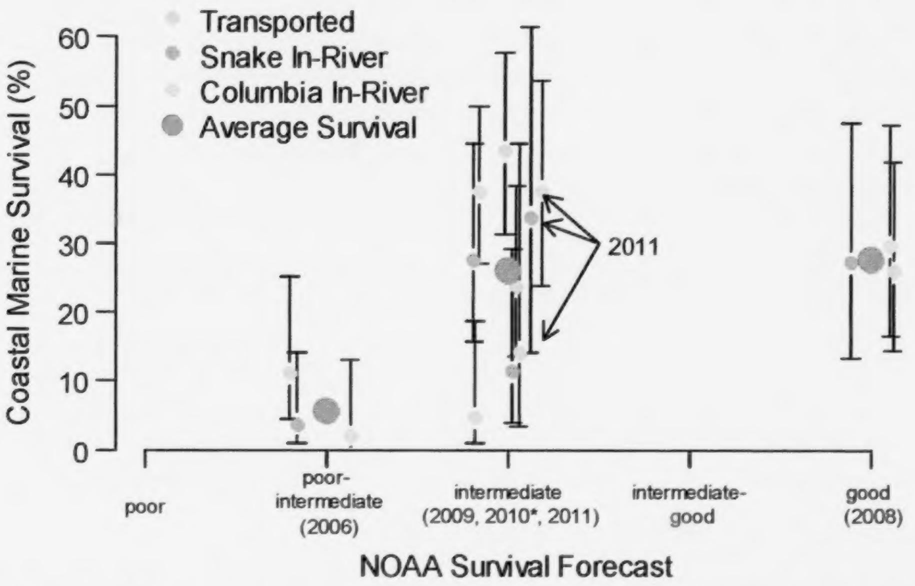

*Figure 4. Acoustic telemetry-based coastal marine survival estimates of Columbia River yearling spring Chinook salmon compared to published NOAA survival forecasts based on biological, physical, and chemical indicators (See http://www.nwfsc.noaa.gov, "Ocean conditions and Salmon Forecasting") in 2006, 2008-2011. * indicates that ocean conditions shifted from "poor" to "good".*

Some physical and biological data for the Salish Sea are linked to salmon survival to adult return elsewhere in this volume (Sweeting 2012, elsewhere in this research document). The biological measurements reported were taken in July and September, after most Chilko and Cultus Lake sockeye have migrated from the SoG area (acoustic tagged smolts moved out of the SoG by mid-June). The physical oceanographic indicators reported may, however, correlate with early marine survival in the SoG: our estimated SoG sockeye smolt survival was highest in 2007 (of our six year data set), when June physical oceanographic parameters in the SoG were judged to be intermediate-good, while estimated smolt survival was very poor in 2006 when physical oceanographic parameters were similarly reported to be unfavourable. As the 2009 adult sockeye return from the 2007 ocean entry year was an order of magnitude lower than what was originally forecast, early marine survival in the SoG may not have driven the poor adult return of 2009 and survival problems beyond the Salish Sea may have played a significant role.

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2.3.12 Declining concentrations of persistent PCBs, PBDEs, PCDEs, and PCNs in harbour seals from the Salish Sea

Peter S. Ross, Fisheries & Oceans Canada

Persistent, bioaccumulative and toxic (P-B-T) contaminants present a health risk to aquatic biota, notably those at the top of food webs. Many chemicals with P-B-T properties have been regulated in the past, such as DDT or polychlorinated biphenyls (PCBs), but some have only recently come under regulatory scrutiny, such as the polybrominated diphenyl ethers (PBDEs). Such contaminants all share certain chemical properties (P-B-T), and at high concentrations they have affected the health of some populations of high trophic level marine mammals. For example, PCBs have been implicated in reproductive impairment in several marine mammal populations in the Baltic Sea, the St Lawrence estuary, and parts of the USA. In addition, reduced immune function and increased susceptibility to disease have been documented in PCB-contaminated marine mammals. PCBs have been identified as a conservation threat to British Columbia's killer whales (*Orcinus orca*) under the Species at Risk Act (SARA), highlighting the need to study and manage these and related contaminants in recovery efforts.

While very high levels of PCBs have been observed in killer whales from the NE Pacific (Ross et al. 2000), there is scant information about trends of these and related compounds in the region. The harbour seal (*Phoca vitulina*) has provided an integrated measure of food web contamination over space, and has identified Puget Sound, Washington, as being particularly contaminated with PCBs (Ross et al. 2004). Harbour seals represent useful 'indicators' of food web contamination by persistent contaminants because of their high trophic position, wide distribution along the coast, and long lifespan.

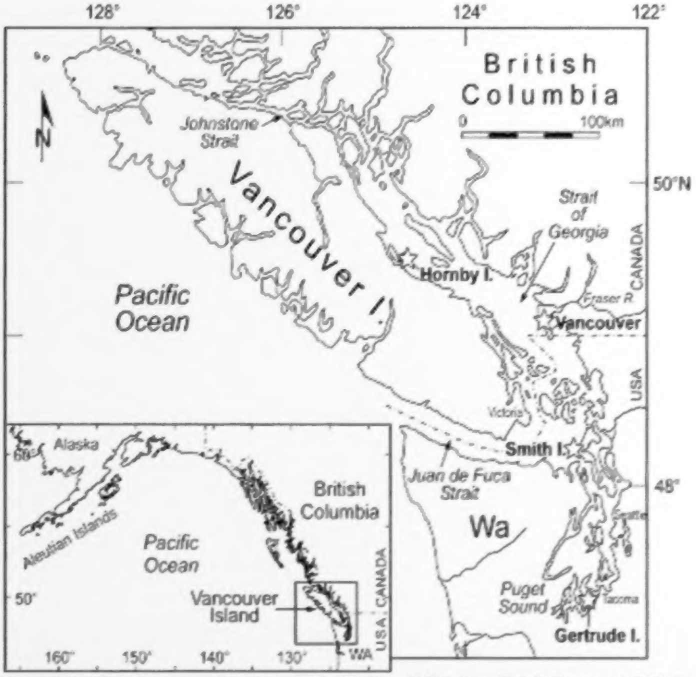
128°
126°
124°
122°
N
British Columbia
0
100km
Johnstone Strait
Vancouver I.
50°N
Strait of Georgia
CANADA
Hornby I.
Fraser R
Vancouver
Pacific Ocean
USA
Victoria
Smith I.
Juan de Fuca Strait
48°
Wa
Seattle
Puget Sound
Tacoma
Gertrude I.
Alaska
60°
Aleutian Islands
British Columbia
Pacific Ocean
50°
Vancouver Island
CANADA
USA
WA
160°
150°
140°
130°

Figure 1: The concentrations of PCBs, PBDEs, PCDEs and PCNs were measured in harbour seals at two British Columbia sites (Hornby Island and Vancouver) and two Washington State sites (Smith Island and Gertrude Island).

Recent analyses of biopsy samples taken from young harbour seals live-captured at Gertrude Island (Washington) reveal that PCBs declined by 81% between 1984 and 2009 (Ross et al. in press; Fig. 3). As PCBs were identified as the top toxicological concern to harbour seals (Mos et al. 2010), this reveals a substantial reduction in the health risks associated with endocrine-disrupting contaminants.

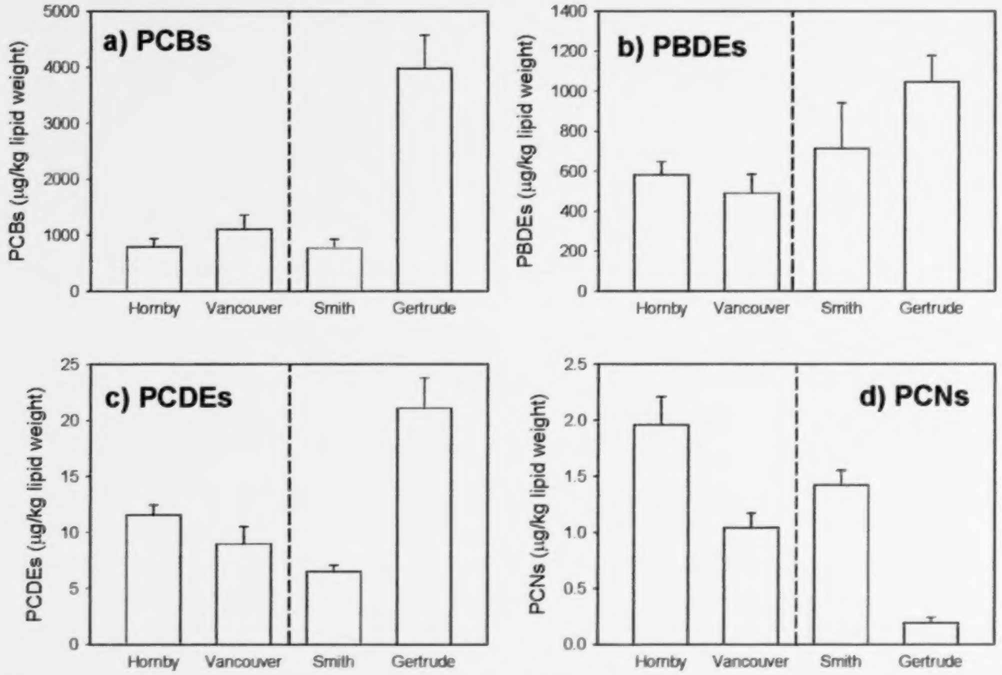

Figure 2: Harbour seals sampled on Gertrude Island (south Puget Sound) in 2004 had the highest levels of PCBs, PBDEs and PCDEs, but the lowest levels of PCNs.

In contrast to the reduction in PCB-related risks, however, the concentration of PBDEs doubled every 3.1 years in harbour seals sampled at Gertrude Island from 1984 to 2003. The emergence of the PBDEs as a concern is consistent with observations elsewhere, but the surprisingly high PBDE : PCB ratios in seals suggests that there exist important local sources of this flame retardant. Recent studies of sediments and waste water effluent suggest that municipal waste water has delivered large quantities of PBDEs to the Strait of Georgia (Johannessen et al. 2008). The suggestion of a peak in PBDE levels in seals between 2003 and 2009 followed by a decline (see Fig. 3) would be consistent with the 2004 phase-out of two of the three PBDE products in Canada and the USA. This may be substantiated by future measurements.

The concentrations of another persistent contaminant of concern – the polychlorinated diphenylethers (PCDEs) – declined by an apparent 3.5 times in harbour seals sampled at Gertrude Island between 1984 and 2003, although this was not statistically significant. The drop in concentration of polychlorinated napthalenes (PCNs) in harbour seals sampled at Gertrude Island between 1984 and 2003 is statistically significant. The estimated half life is 3.4 years.

Harbour seals provide an overview of the 'state of the food web' in terms of contamination with endocrine disrupting compounds. While these trends suggest that the 'quality' of the Salish Sea food web has been improving, our recent observation of PCB-related effects on hormone-related genes in killer whale biopsies (including the estrogen receptor, the thyroid hormone receptor and the aryl hydrocarbon receptor), underscores the lingering effects of persistent contaminants (Buckman et al. 2011).

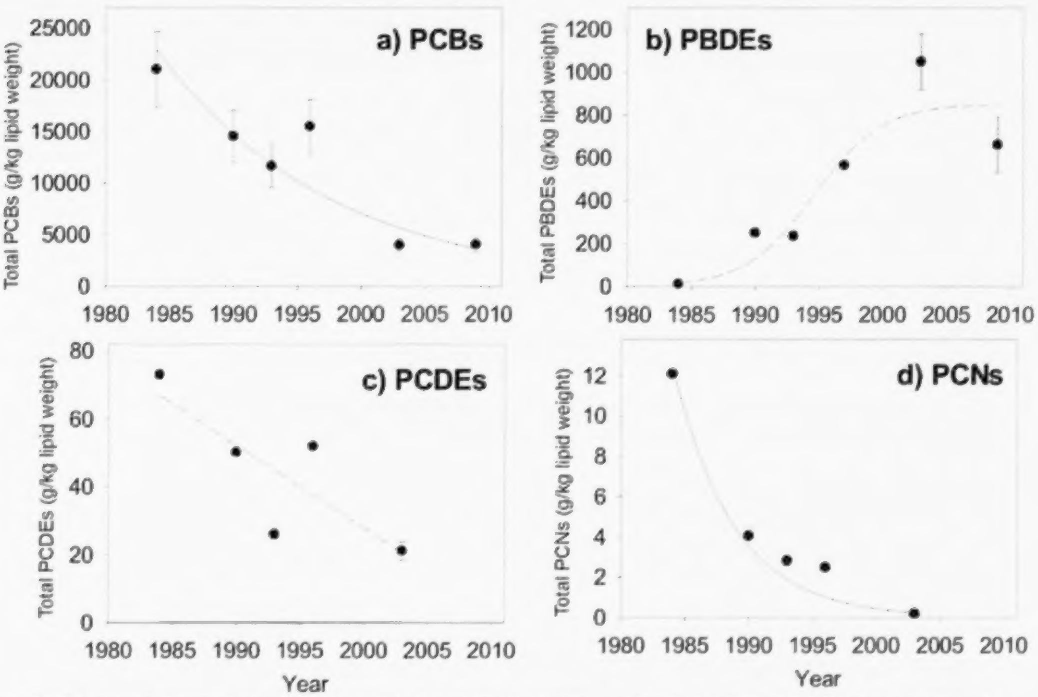

Figure 3: A temporal trend study was carried out in the harbour seals from the PCB-contaminated Gertrude Island site (south Puget Sound) between 1984 and 2009. Results reveal significant reductions in the concentrations of PCBs and PCNs, and a decreasing trend for PCDEs. A rapid rise in PBDE concentrations was followed by what appears to be a reversal in this trend after 2004.

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2.4 PROGRESS IN REPORTING OCEAN INDICES

2.4.1 Ecosystem indicators: What are they, and who is asking for them?

J. Boutillier, C. Fu, J. Curtis, and J. Boldt, Fisheries and Oceans Canada

Fisheries and Oceans Canada (DFO) has committed in the Strategic Objectives for the department, to move towards developing an Ecosystem Approach to the Management (EAM) of human activities in Canada's aquatic environments. The three key pillars that need to be considered in the developing an EAM are Biodiversity, Habitat, and Ecosystem Structure and Function. The need to conserve and protect these three pillars are driven by a number of national and international drivers including our legislative responsibilities under the Fisheries Act, Species at Risk Act, and the Oceans Act and Canada's ratified international commitments to the Convention on Biological Diversity and the United Nation General Assembly resolutions on fisheries and fisheries management.

Ecosystem Structure and Function are the attributes related to the biophysical state of an ecosystem, which is the sum of all the living plants and animals (Biodiversity), the physical and chemical components (Habitat), and their interactions within a particular area. To understand and manage the impacts of human activities in a manner that will allow us to meet conservation goals with respect to ecosystem structure and function, it is necessary to develop ecosystem indicators that measure the characteristic of an ecosystem that is related to, or derived from, a measure of biotic or abiotic variables that can provide quantitative information (metrics) on the state of the ecosystem structure and function. DFO has been active in various national and international initiatives to address the need for and the development of these metrics. Nationally, DFO has led the development of national policies such as the Wild Salmon Policy, Sensitive Benthic Areas Policy, Forage Fish Policy, and Bycatch Policy. Internationally, DFO Science has participated in international working groups (e.g. CAMEO, IndiSeas, PICES) to develop common approaches to the development of ecosystem indicators (Fu et al. in press, http://www.indiseas.org, Shin et al. 2012, https://www.pices.int/publications/presentations/2011-FUTURE-wsh/2011-FUTURE-workshop.aspx).

Ecosystem indicators are derived to evaluate ecosystem status in support of EAM and to assess effects on the ecosystem of stressors associated with human activities. This in turn requires an understanding of the extent (magnitude and degree of exposure) and nature (direct and indirect pathways of effects) of the stressors. These ecosystem indicators are used to distinguish between the effects of the stressors and the changes as a result of natural variations that occur in the absence of these activity-based stressors. They are also used to determine the significance of these changes (recovery potential) and thresholds that would indicate tipping points resulting in change from one ecosystem state to another (e.g. the policy on the precautionary approach for fisheries target species).

Within and outside the Department, sector resource managers frequently ask DFO scientists to provide advice on the pathways of effects on fish and fish habitat (http://www.dfo-mpo.gc.ca/habitat/what-quoi/pathways-sequences/index-eng.asp), quantify the extent and nature of various impacts, and develop quantitative conservation objective metrics for the three pillars of EAM.

Fisheries Managers request this type of information to:

- support fishery management to fulfil requirements of the Sustainable Fisheries Framework policies on Sensitive Benthic areas, By-catch (biodiversity impacts), Forage fish (trophodynamic changes)
- support industry to obtain Marine Stewardship Certification

- better understand how natural variations in environmental conditions affect fisheries production parameters in fisheries assessment models, e.g. herring larval survival in cold and warm years

Habitat and Aquaculture Managers request this support to manage non-fishing activities for the protection of fish and fish habitats including:

- log handling, small craft harbours, power projects, port expansion, oil and gas pipeline, transportation, and water diversion projects, etc.
- aquaculture with higher emphasis being placed on quantifying the risk associated with pathogens, parasites, aquatic invasive species (AIS) vectors and fomites (inanimate object or substance capable of carrying infectious organisms such as germs or parasites).

Ocean's managers request information in support of:

- implementing DFO marine protected areas (MPAs);
- developing a network of federal and provincial MPAs; and
- integrated management within Pacific North Coast Integrated Management Area (PNCIMA) and other areas

SARA Managers are concerned with meeting legal listing criteria as outlined within the Species at Risk Act:

- COSEWIC and SARA Species Status Reports, Review of Species Status Reports;
- provision of advice on recovery potential analysis that incorporates all natural and human impacts prior to listing;
- post listing identification of and pre listing advice re critical habitat;
- development of a recovery strategy and action plan;
- carrying out programs as outlined in the recovery action plan

Provision of advice to other regulatory authorities that include:

- Most issues falling within the Habitat Management envelop, although there is also a strong AIS component of research especially with respect to management of AIS fomites such as bilge water.

As part of DFO's commitment in the Departmental Strategic Objective on Sustainable Aquatic Ecosystems, DFO Science must report to Treasury Board on the General Status of Aquatic Species and provide an annual Consolidated Index of Aquatic Ecosystem Health.

The report on the General Status of Aquatic Species will be reported on a five-year cycle to the Canadian Endangered Species Conservation Council. The Consolidated Index of Aquatic Ecosystem Health will include three indicators: population status of commercial species, trophic structure, species richness and ecological diversity.

The population status of commercial species will be a review of the annual CSAS advice on various commercial populations. The trophic structure and species richness indicators were developed at a national workshop while meeting the following constraints:

- The indicators must be responsive to management actions that are within DFO's mandate
- The indicators must be responsive over timeframes that can inform management strategies of the Department

- Sufficient data must be available to calculate the indicator now and into the future
- The indicators must allow interpretation of trends relative to historical status and be robust to changes in available information.
- (Ideally) The index needs to be calculated for each Canadian marine eco-region

For Trophic Structure

Six indicators were investigated:

1. slope of size spectra
2. proportion of large fish (>35cm)
3. mean trophic level
4. mean length
5. mean maximum length
6. proportion of predatory fish

The ecosystems and data used were from research surveys in eco-regions from all three oceans. For the Pacific, the eco-regions and data used were:

- PNCIMA: the Hecate Strait groundfish trawl surveys from 1984 to 2009
- West Coast of Vancouver Island: shrimp trawl surveys from 1980 to 2010

Of the six indicators investigated, the proportion of large fish (>35cm) was selected as the most appropriate indicator based on: the fact that all indicators were correlated (>0.6) based on a Spearman and Pearson correlation analysis; preference was given to an indicator that was independent of external data (e.g. FishBase trophic levels); the ease with which it could be understood by the public; and the compatibility with this indicator to other ecosystem research efforts.

For Species Richness and Ecological Diversity

Two important metrics, to evaluate Canadian aquatic species richness and ecological diversity, are changes in the numbers of depleted natural populations and aquatic invasive species (AIS) as proportions of those populations/species that are monitored. AIS is defined as an introduced species that has caused or can cause ecological, economic or social damage.

To account for these two metrics, a proposed performance indicator (PI) assumes that increases in the proportion of depleted species and AIS contribute negatively to richness and diversity and is calculated as:

$$PI = 1 - \left[{(n_1 + n_3)}\Big/{(n_2 + n_4)} \right]$$

where:

n_1 – number of depleted populations in the eco-region

n_2 – total number of populations in the eco-region that were assessed for the status of depletion

n_3 – number of AIS in the eco-region that are increasing in abundance or distribution

n_4 – total number of AIS in the eco-region that are monitored to assess changes in abundance and distribution

DFO has made a commitment to the Parliament of Canada to undertake a more encompassing ecosystem approach to management. This means that DFO Science needs to develop new tools and products to provide advice to managers on the risks associated with all human activities, their stressors and their effects on the three pillars of ecosystem assessments, i.e. biodiversity, habitat and ecosystem form and function. There will be a number of challenges along the way such as: ensuring that all surveys that are carried out include an objective that collects information that can be used to inform a more ecosystem-based approach to management.

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